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Cabrera et al.

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(54) **PAD MICROPRINTING DEVICE AND METHODS, AND PAD FOR THIS DEVICE**

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Oct. 31, 2007 (FR) 07 07691

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B82Y 10/00	(2011.01)
G03F 7/00	(2006.01)

(52) **U.S. Cl.**

CPC ***G03F 7/0002*** (2013.01); ***B82Y 10/00*** (2013.01); ***B85Y 40/00*** (2013.01)

USPC **101/395**

(58) **Field of Classification Search**

None

See application file for complete search history.

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(57) **ABSTRACT**

This pad microprinting device comprises:

- a multi-level pad (**34**) wherein the printing pattern is made out of elastomeric material for which the Young's modulus is between 0.1 and 100 MPa, and
- a stop mechanism (**62-64**) capable of keeping an incompressible space of a thickness D_n between the nth flat bottom (**122**B) and the face of the substrate (**32**) on which an imprint has to be printed, when the pad is compressed against the face of the substrate to print off the imprint, the thickness D_n being between $h_n/2$ and h_n+100 nm where h_n is the height of the protrusions of the printing pattern.

13 Claims, 7 Drawing Sheets

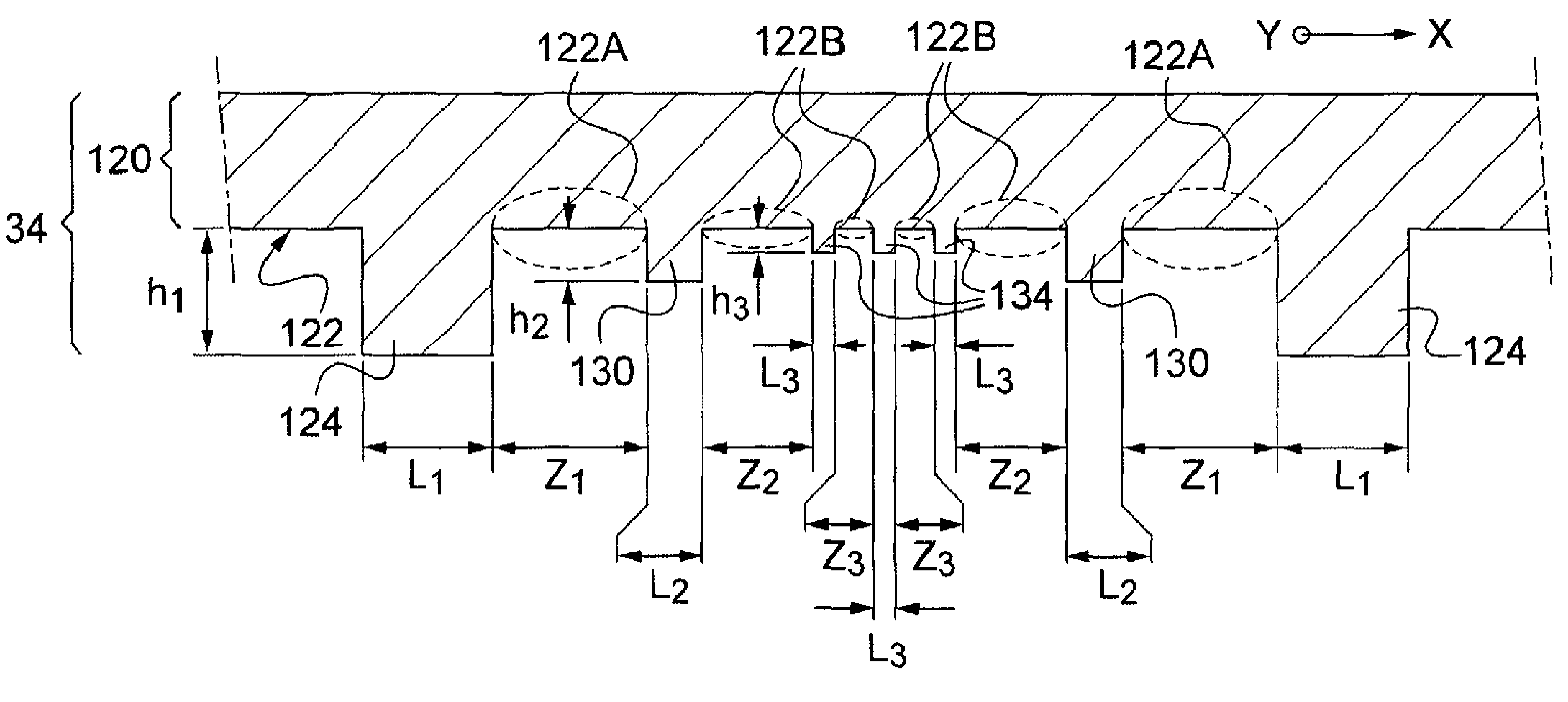


Fig.1

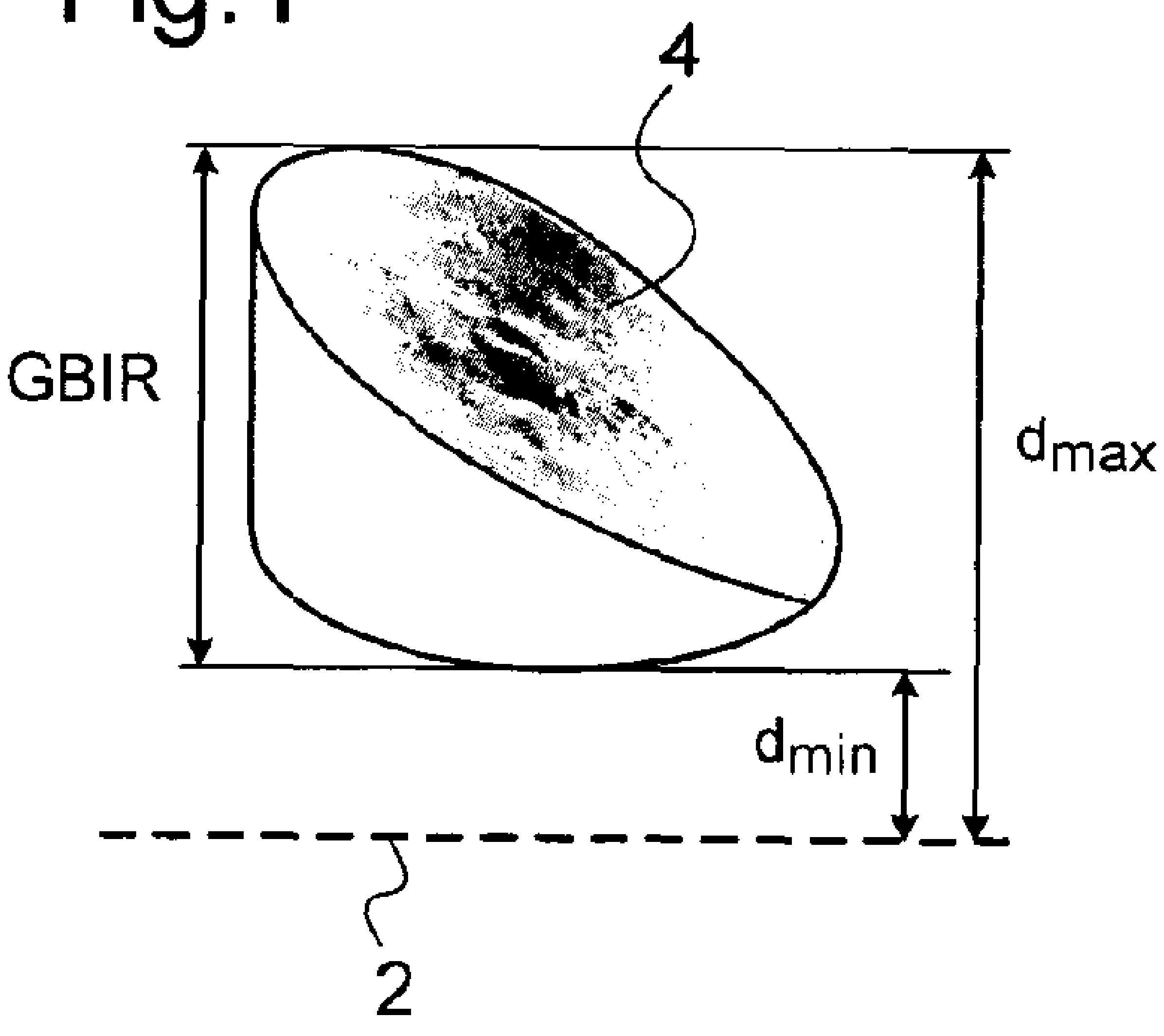


Fig.2

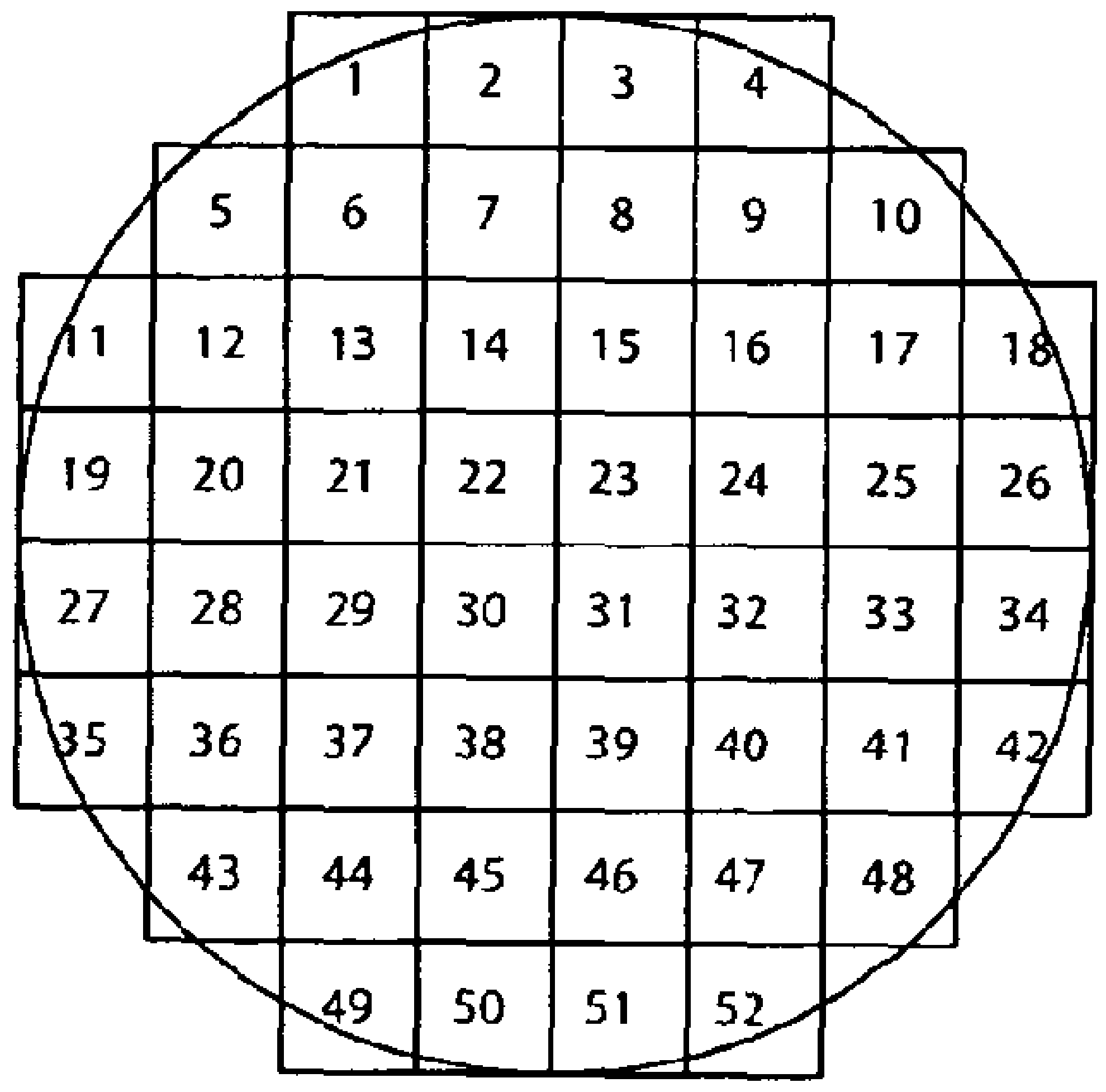


Fig.3

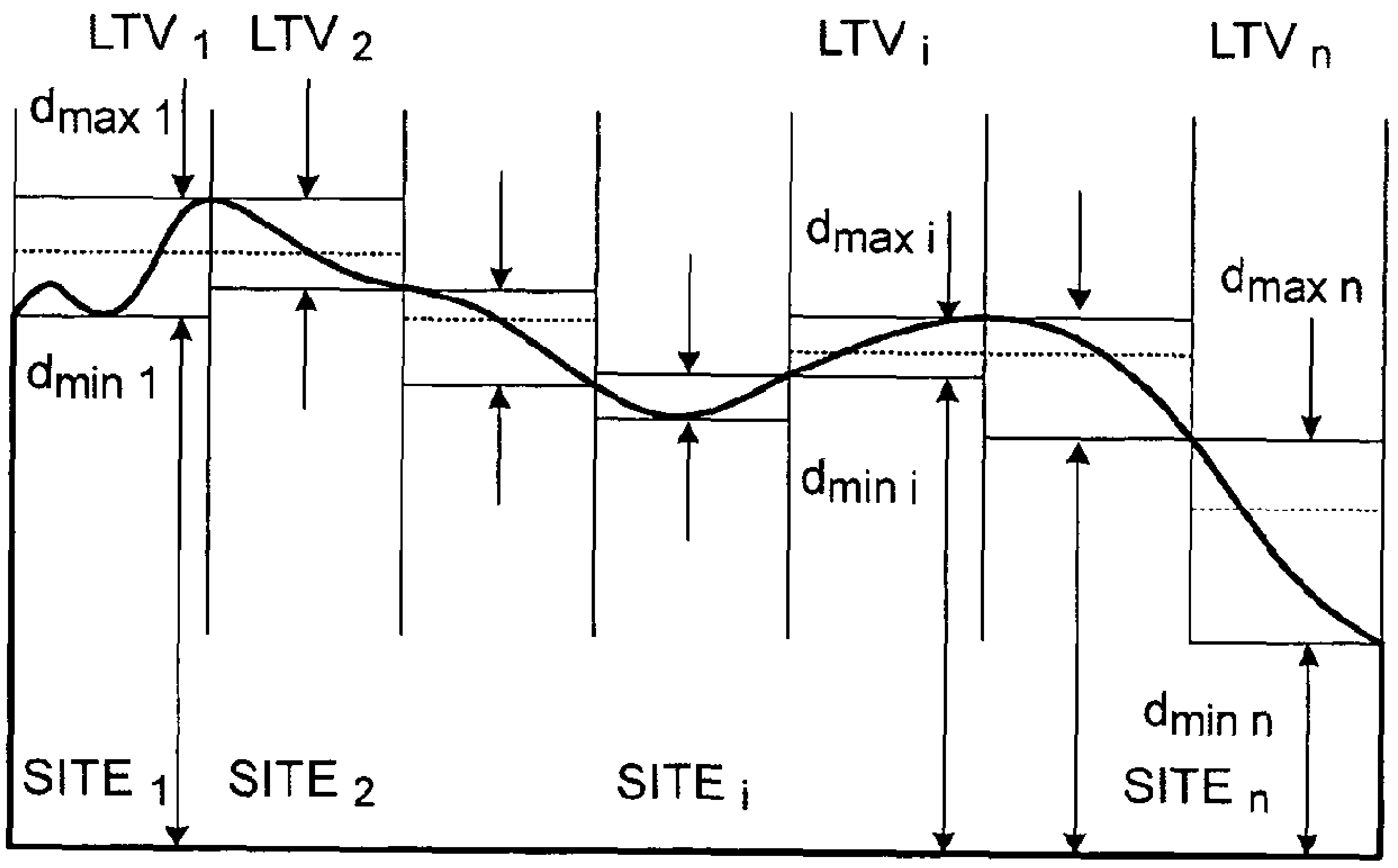


Fig.4

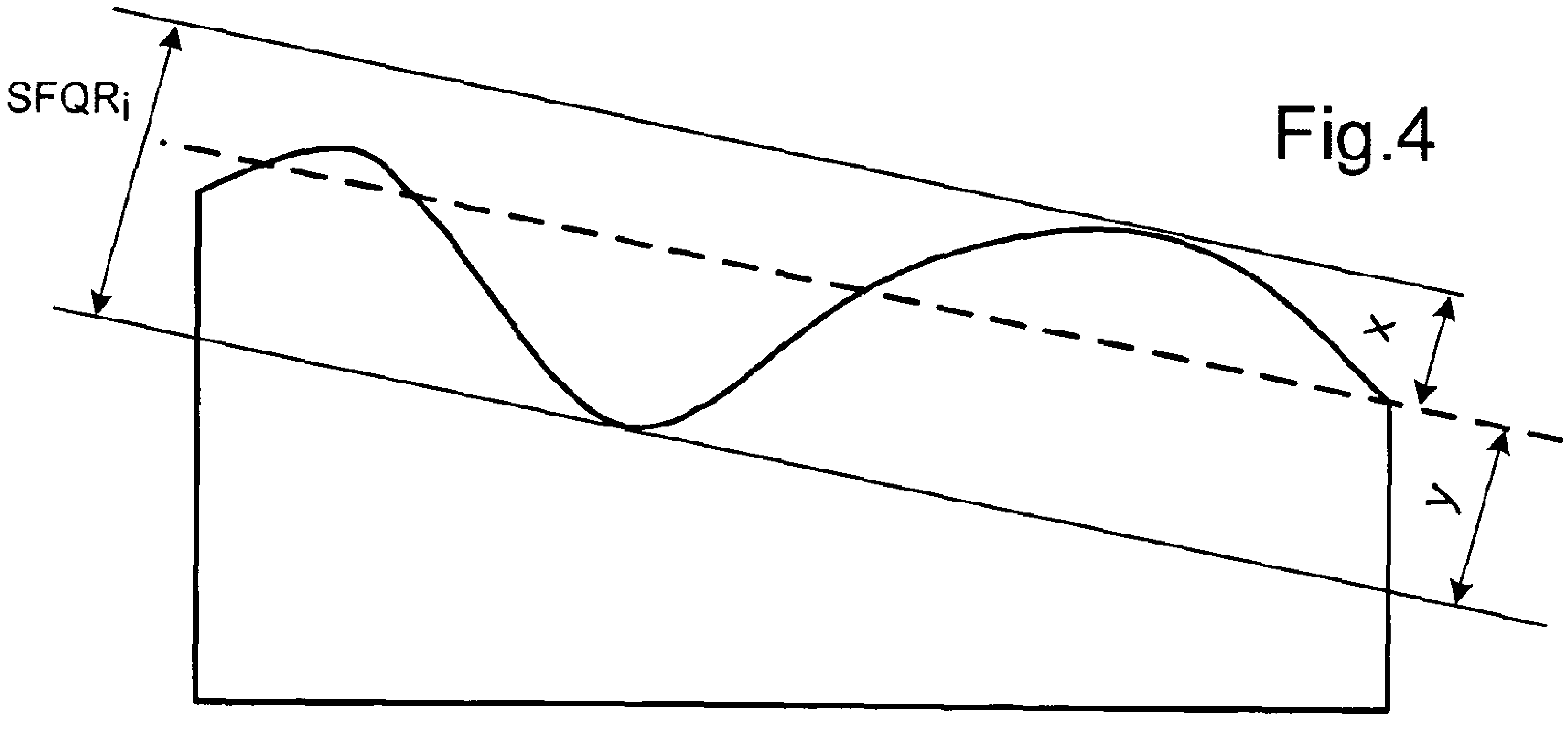


Fig.5

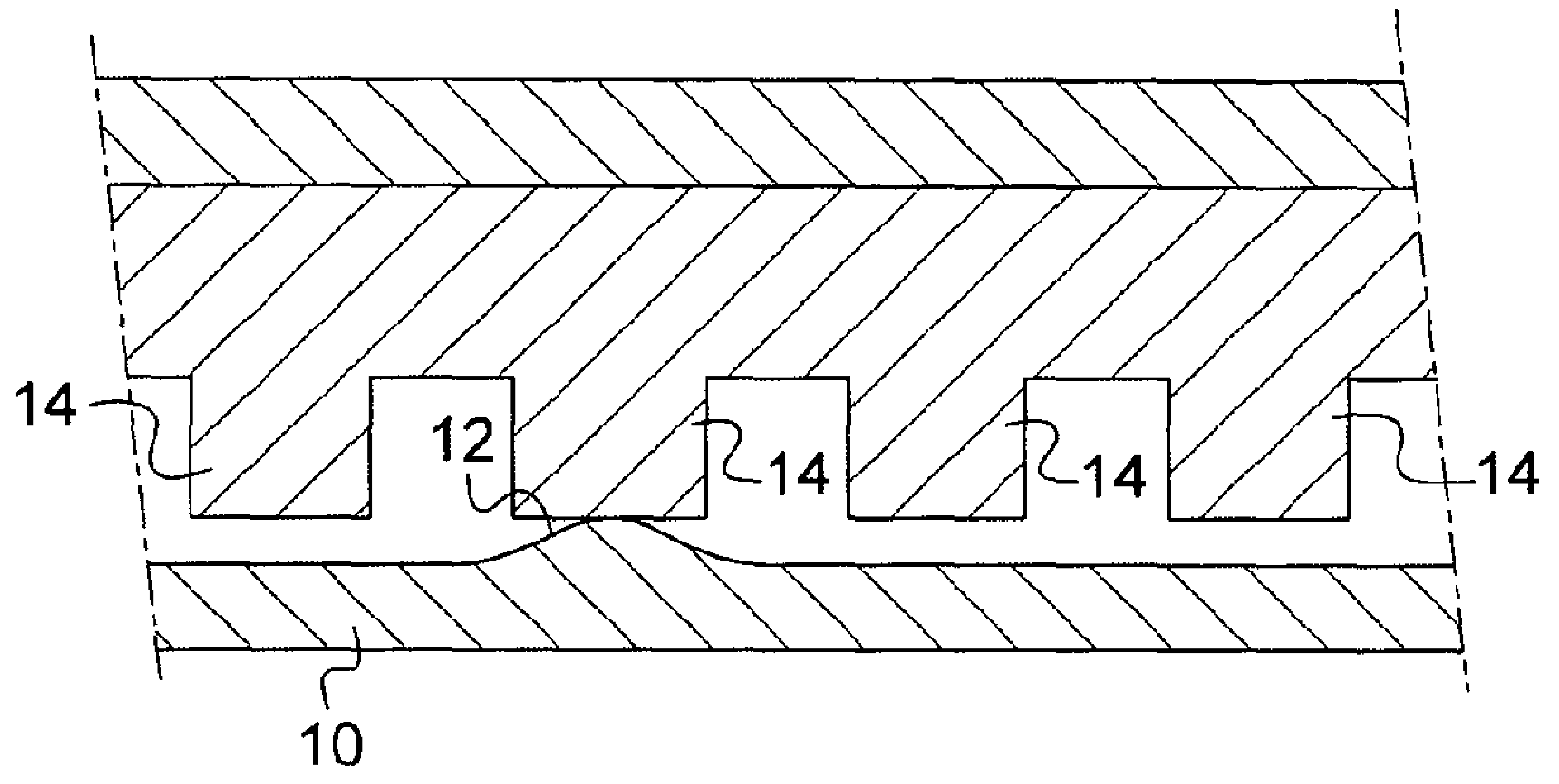


Fig.6

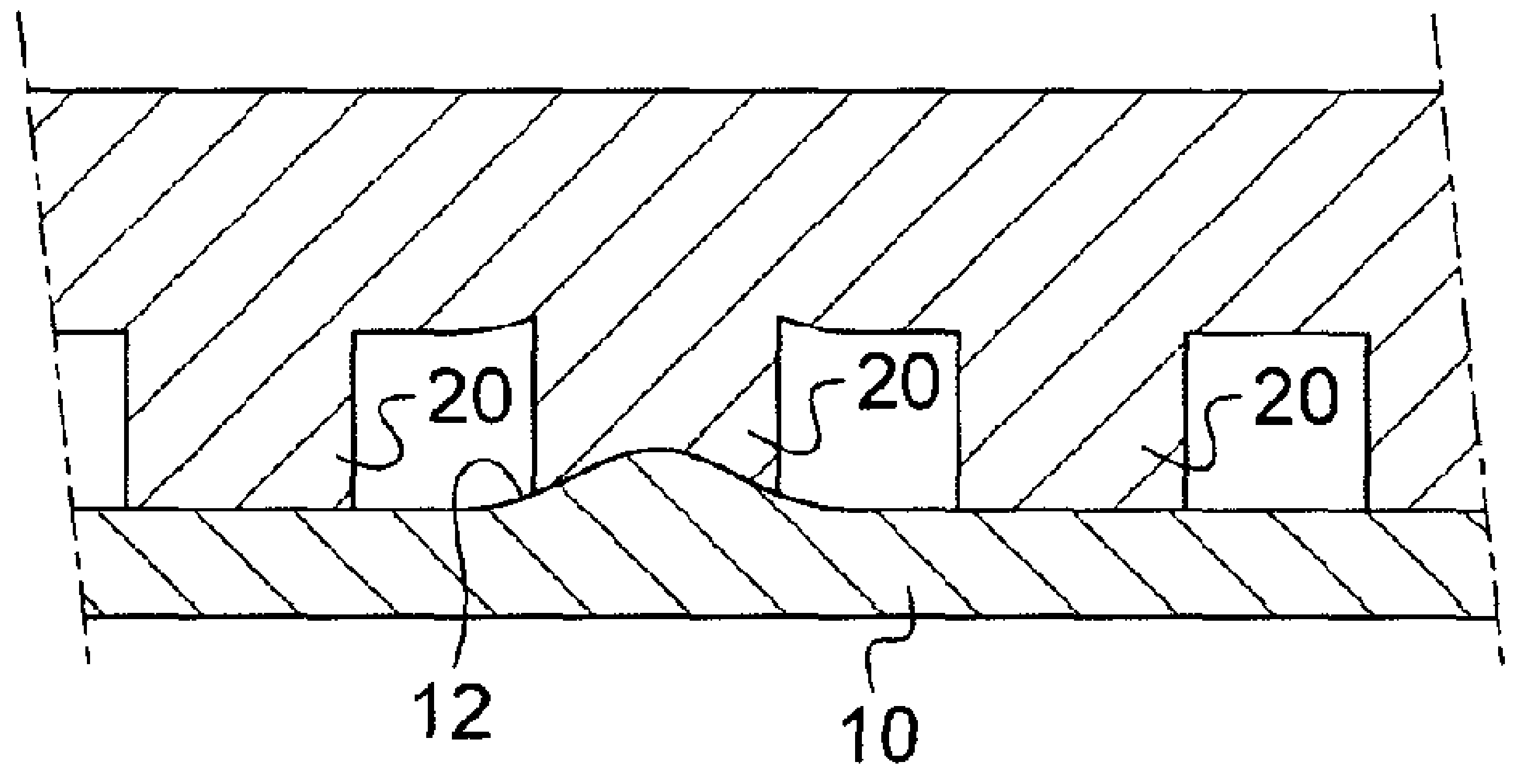
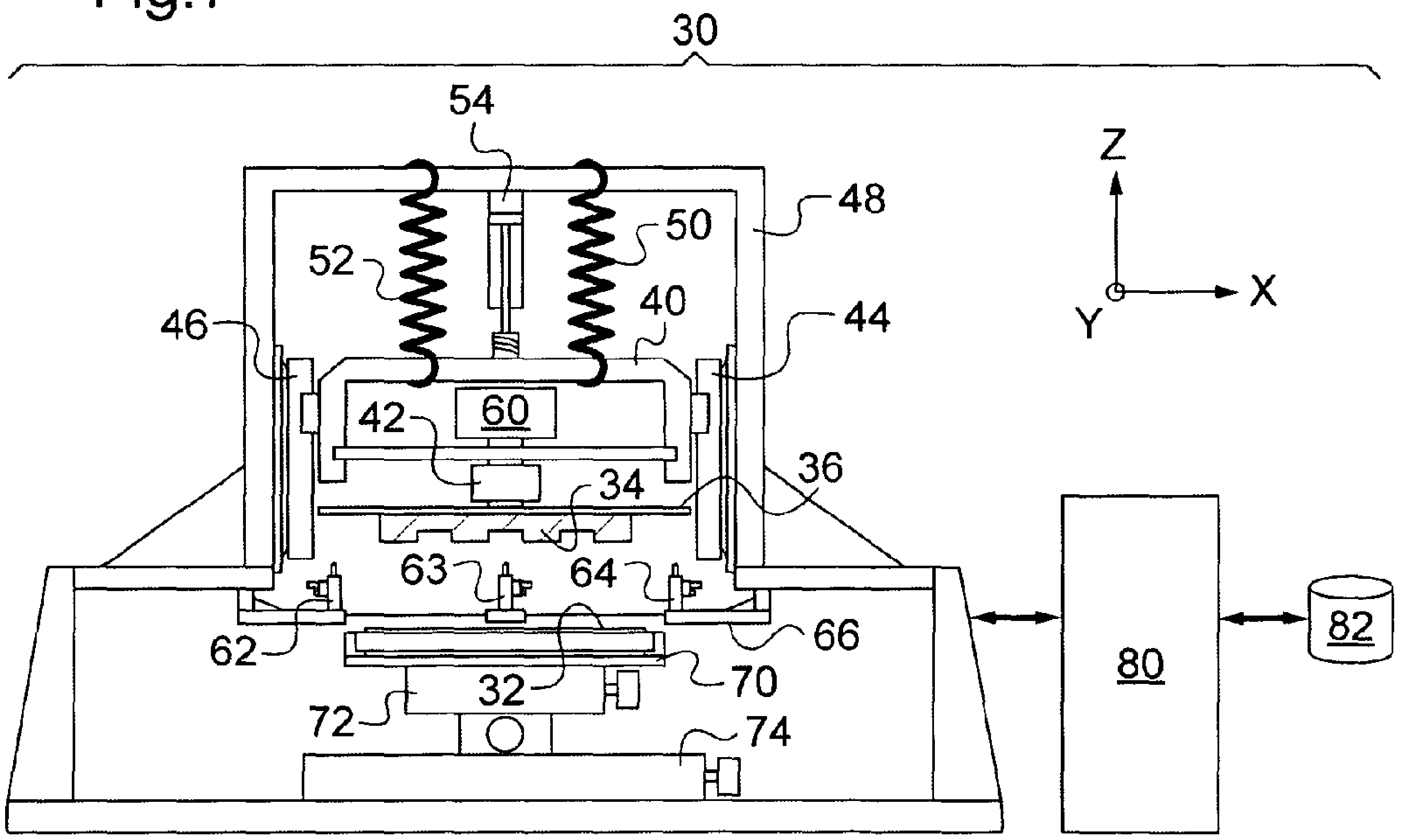


Fig.7



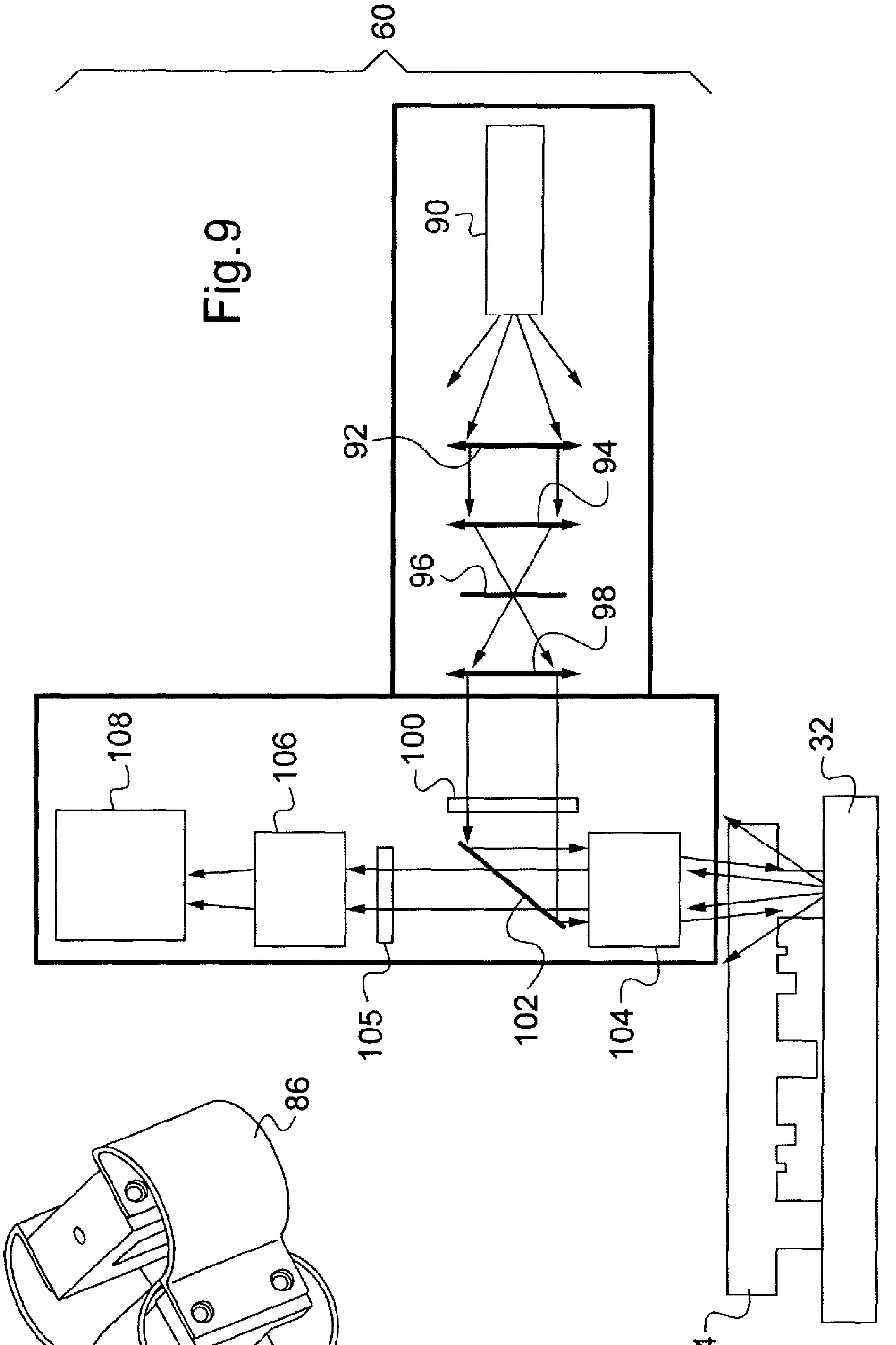


Fig.9

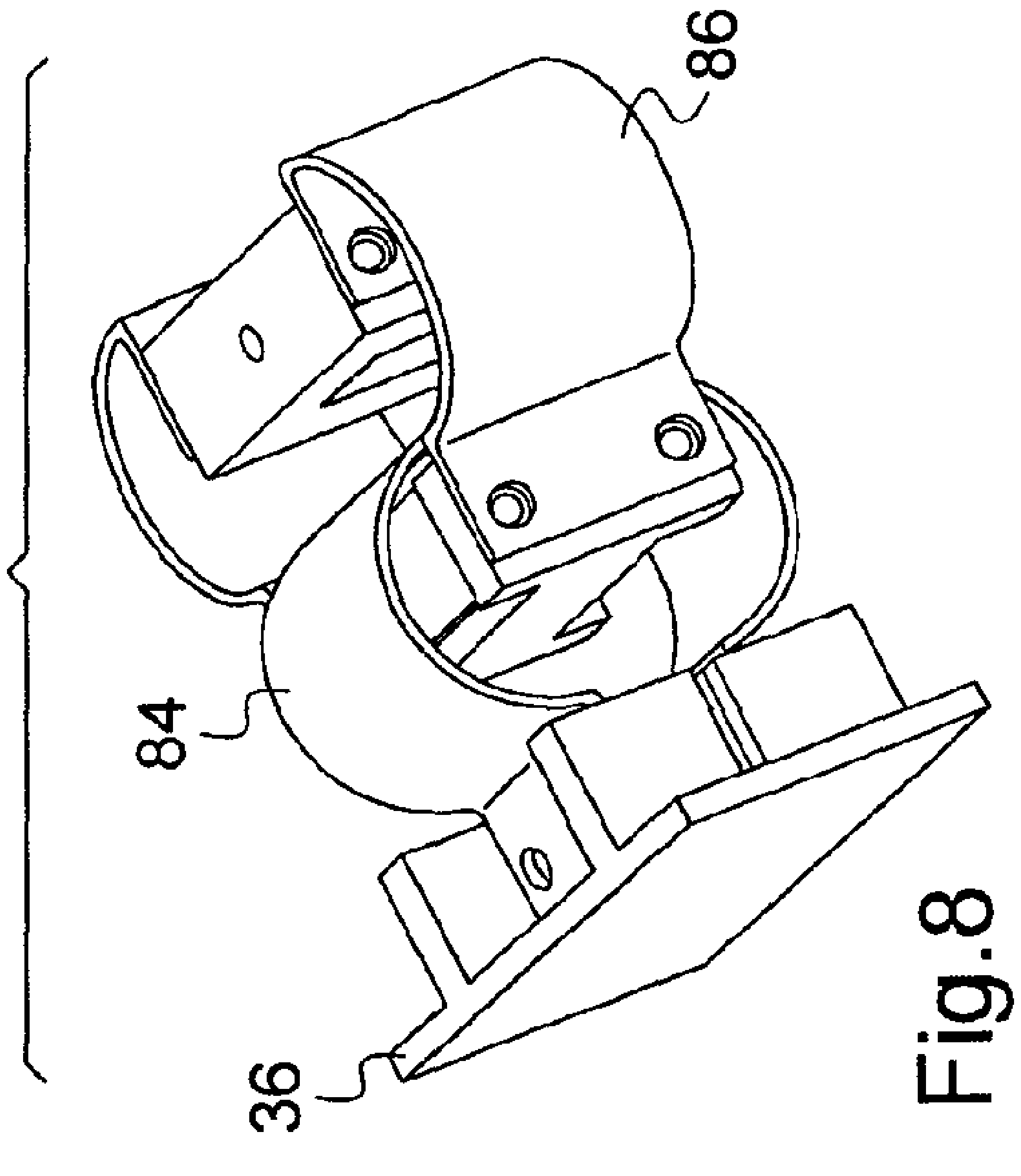


Fig.8

Fig.11

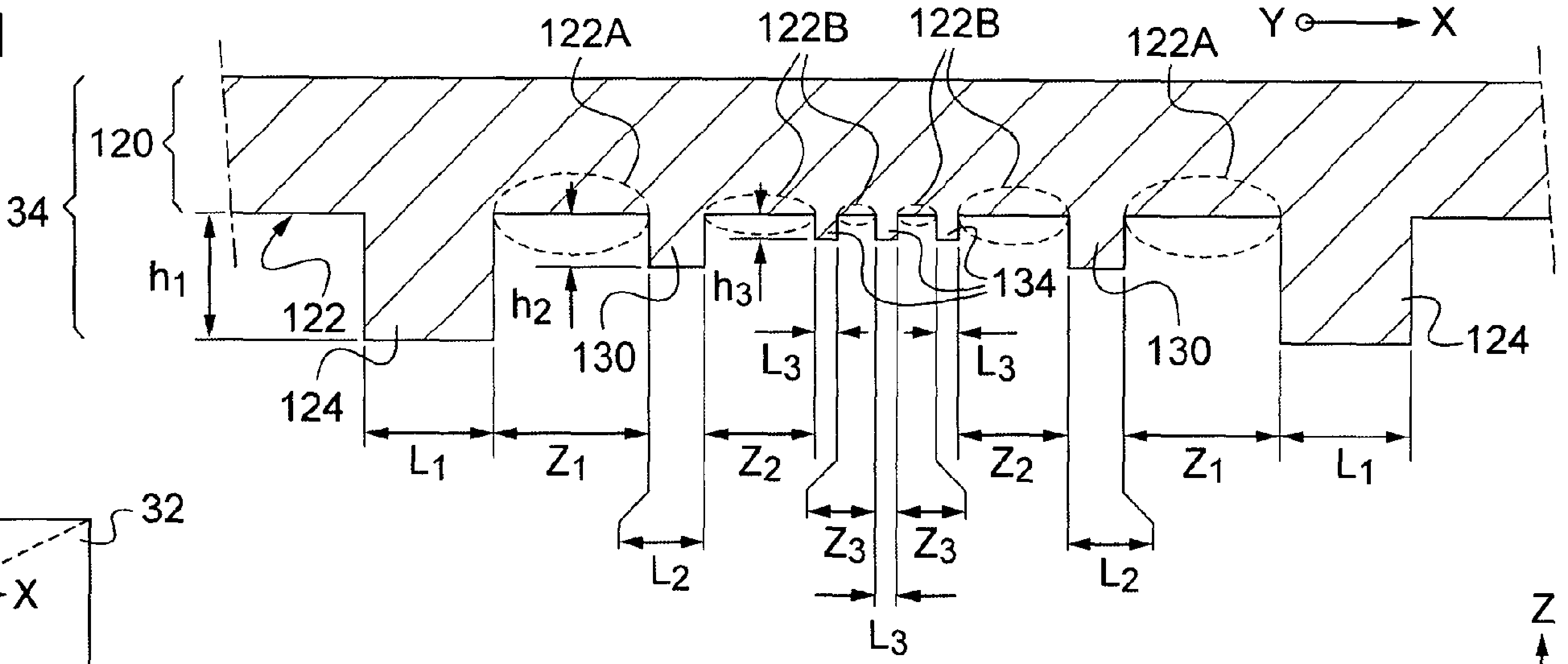


Fig.10

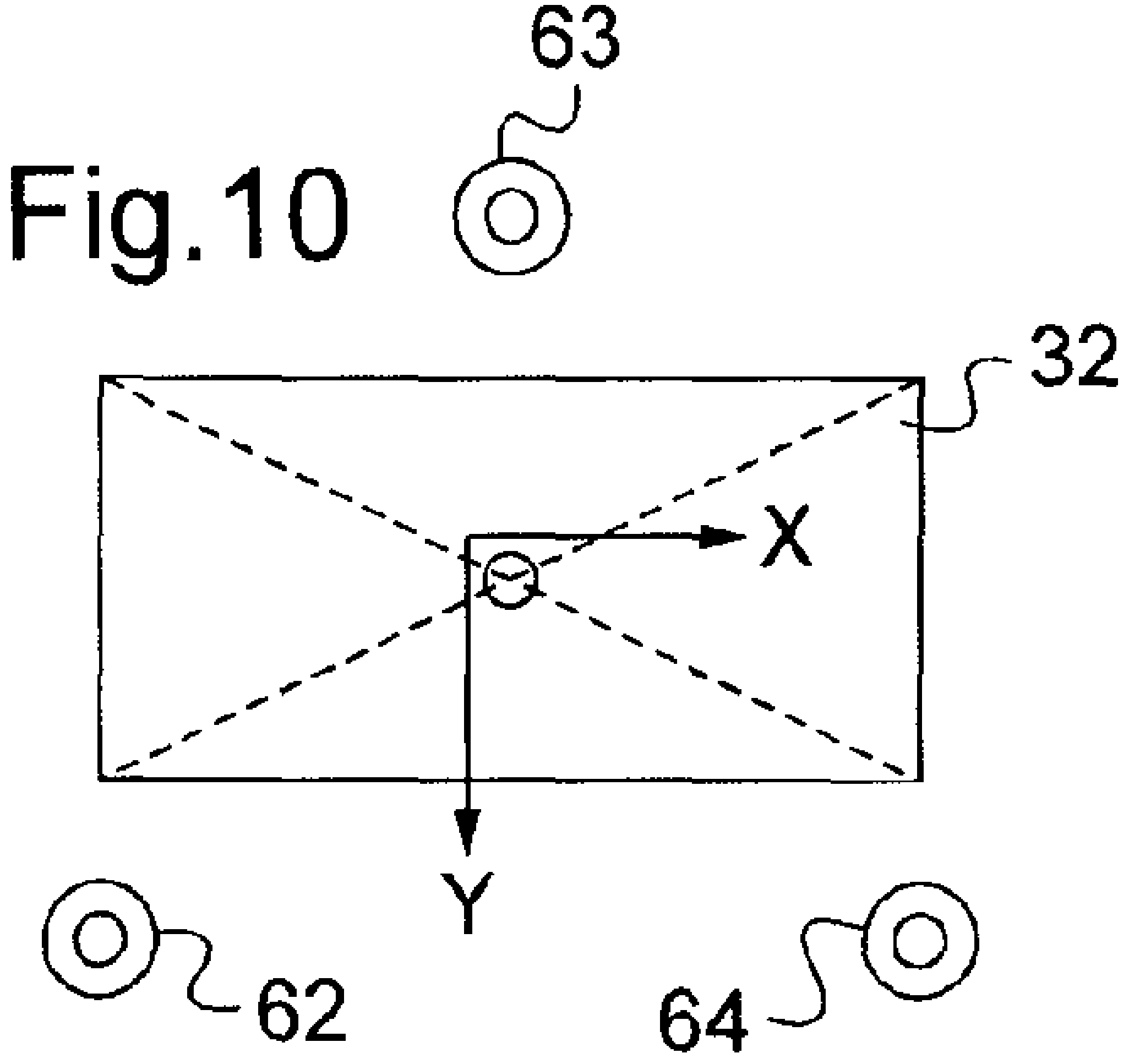
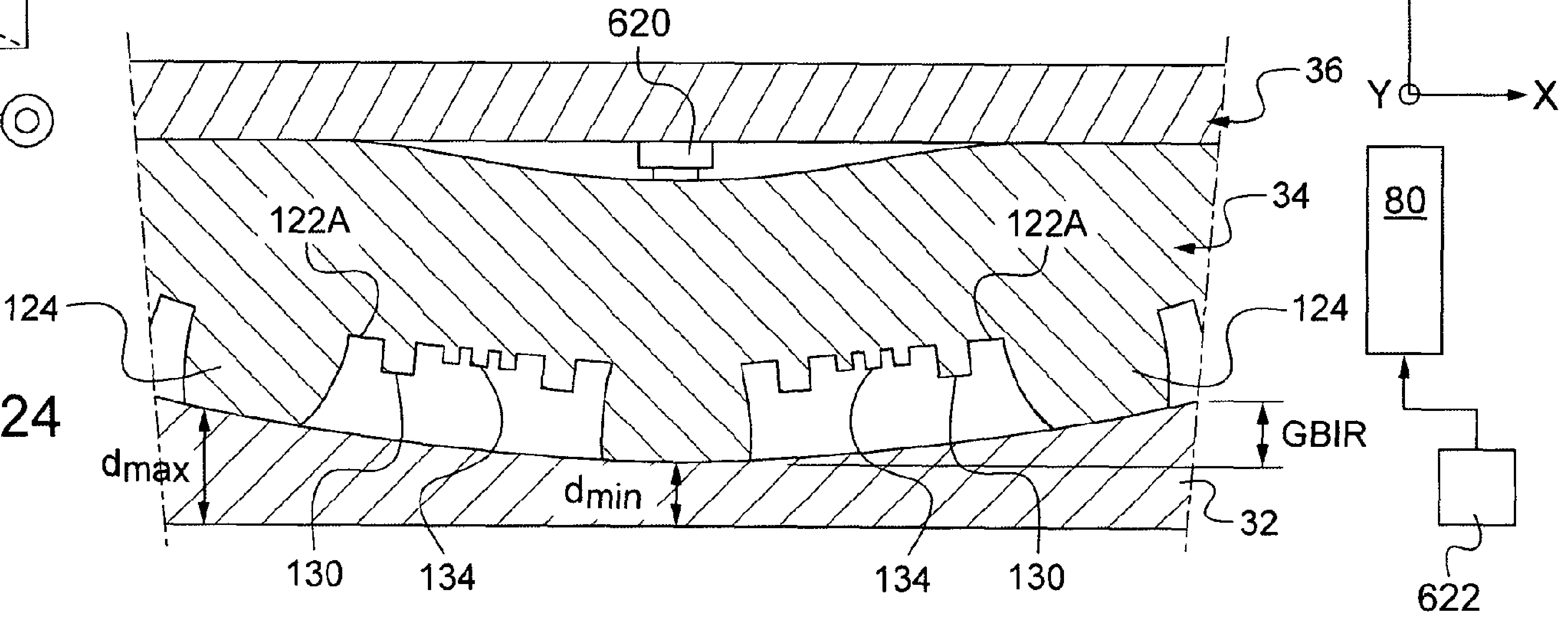


Fig.24



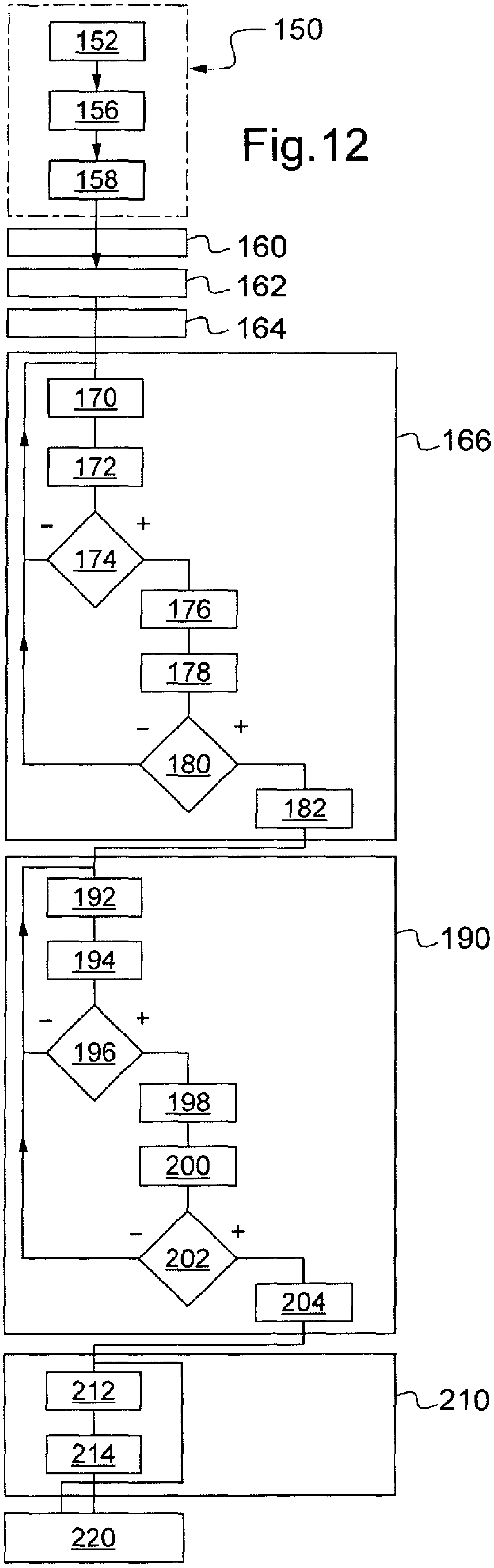


Fig.12
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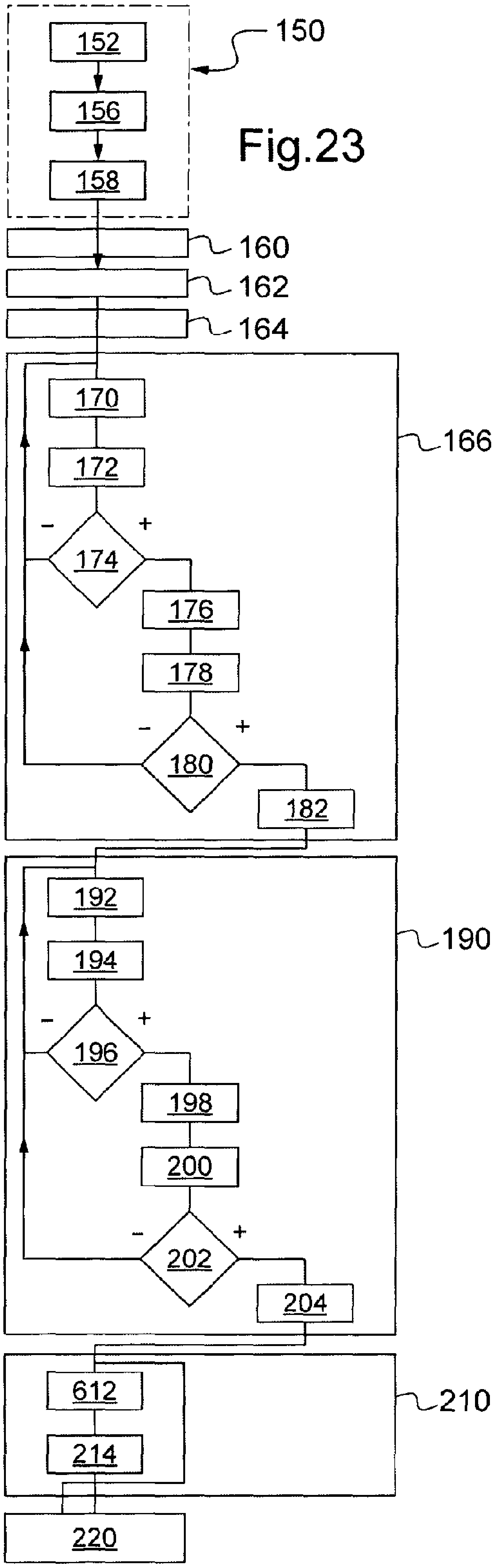
Fig.23
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Fig.13

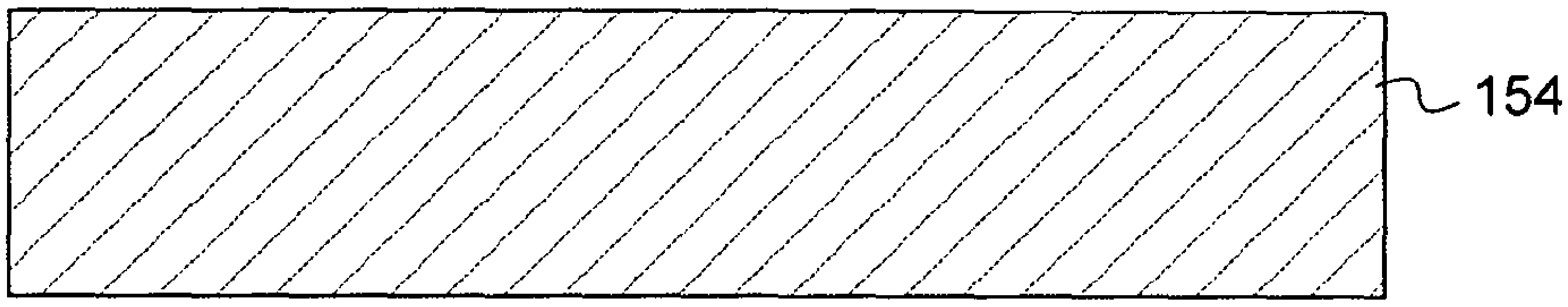


Fig.14

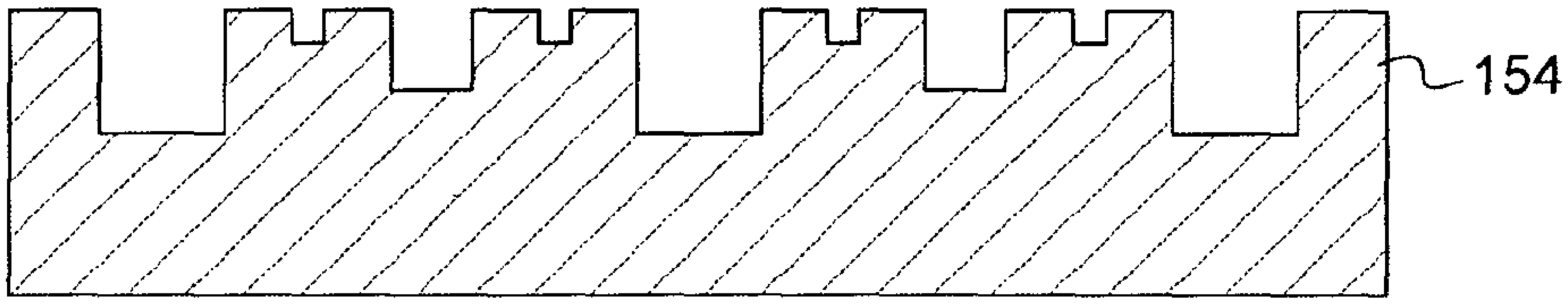


Fig.15

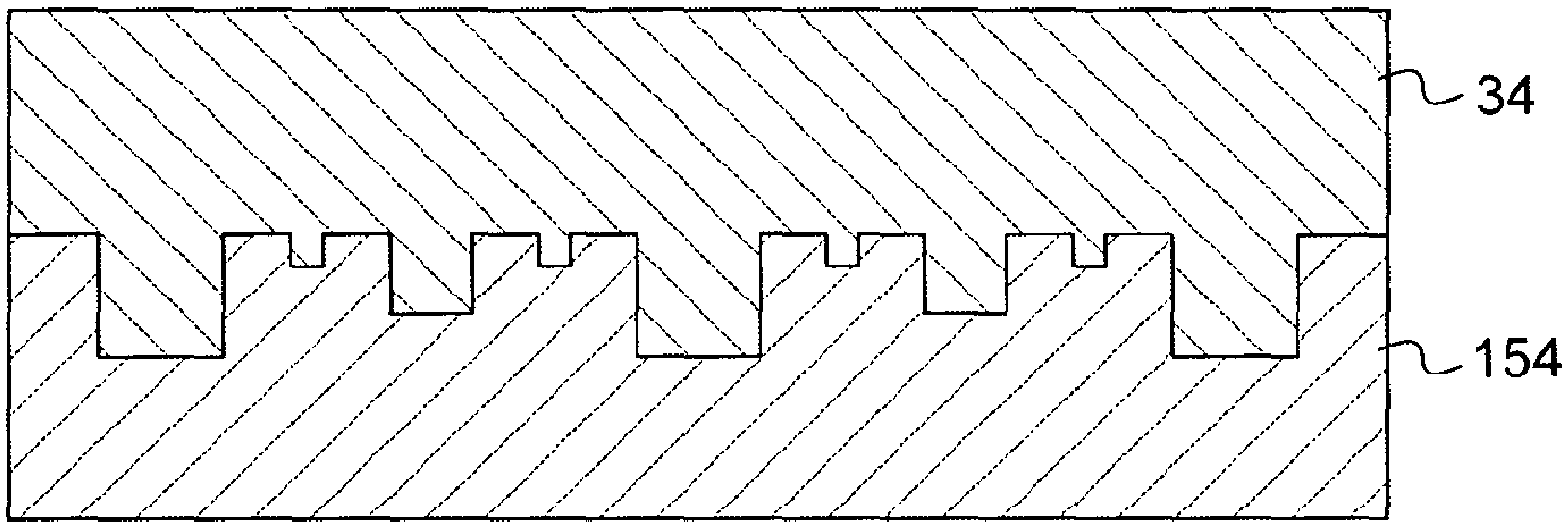


Fig.16

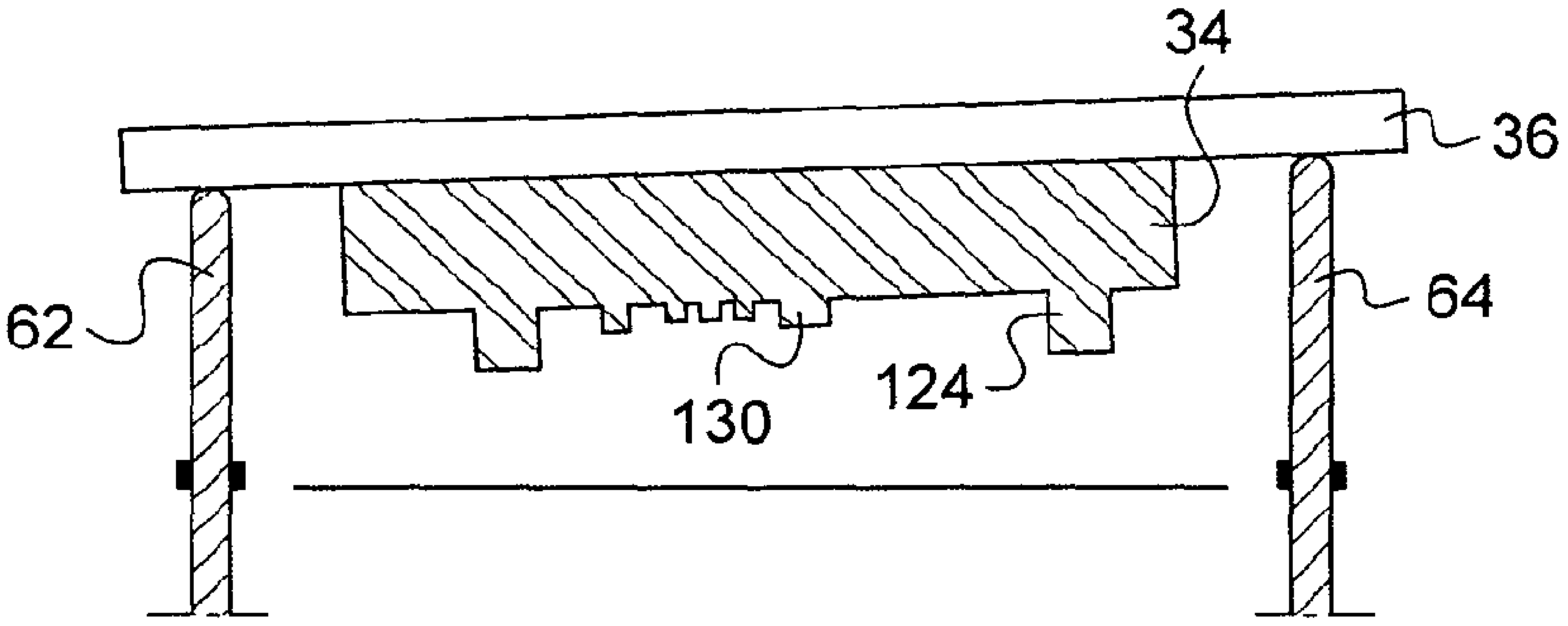


Fig.17

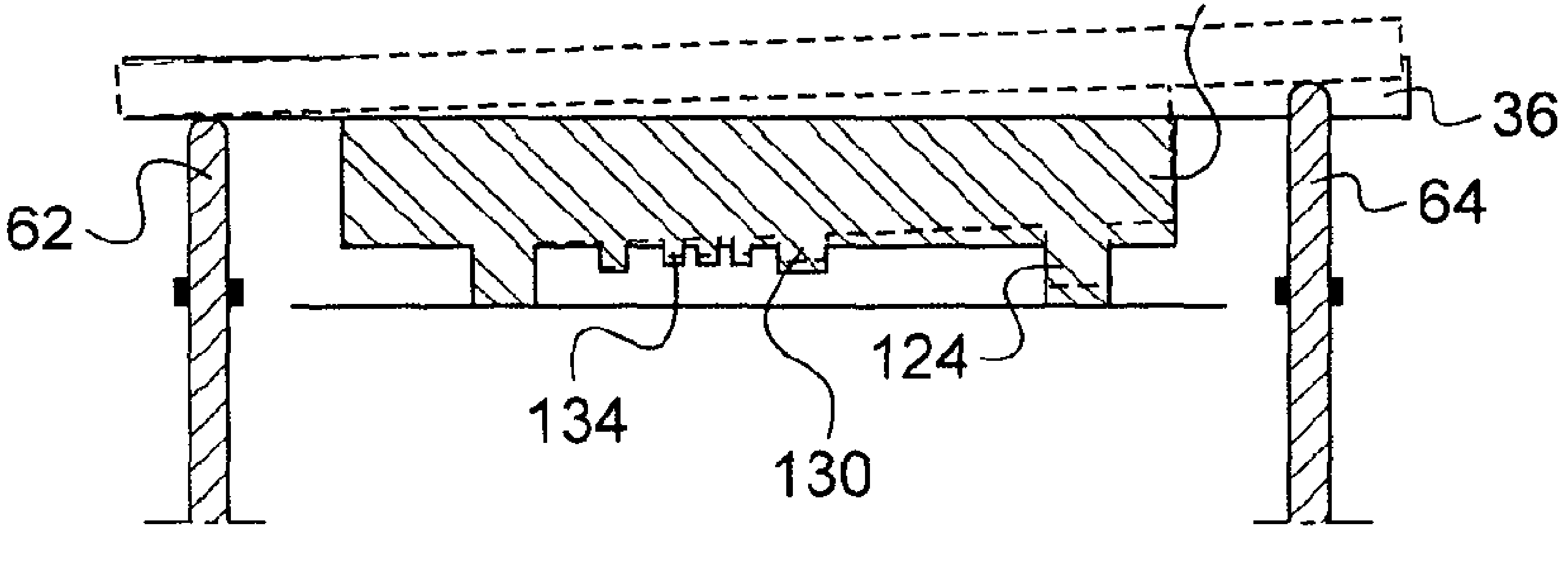
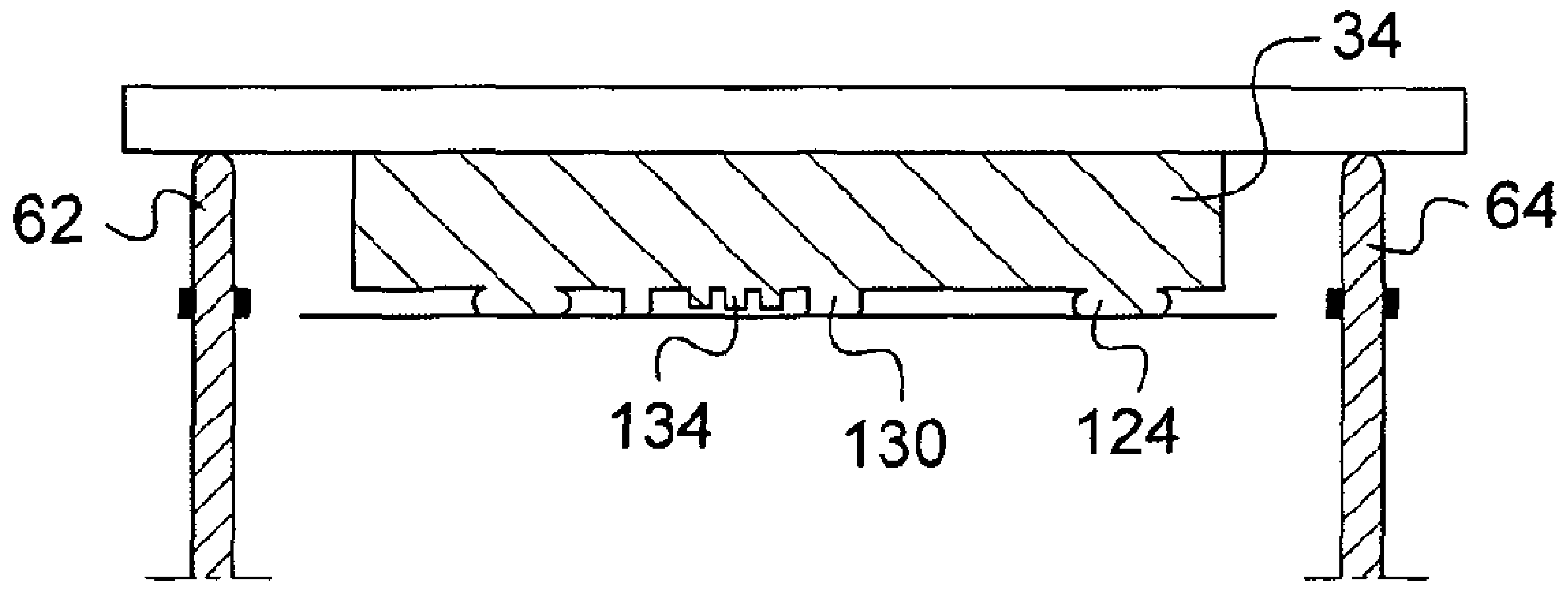


Fig.18



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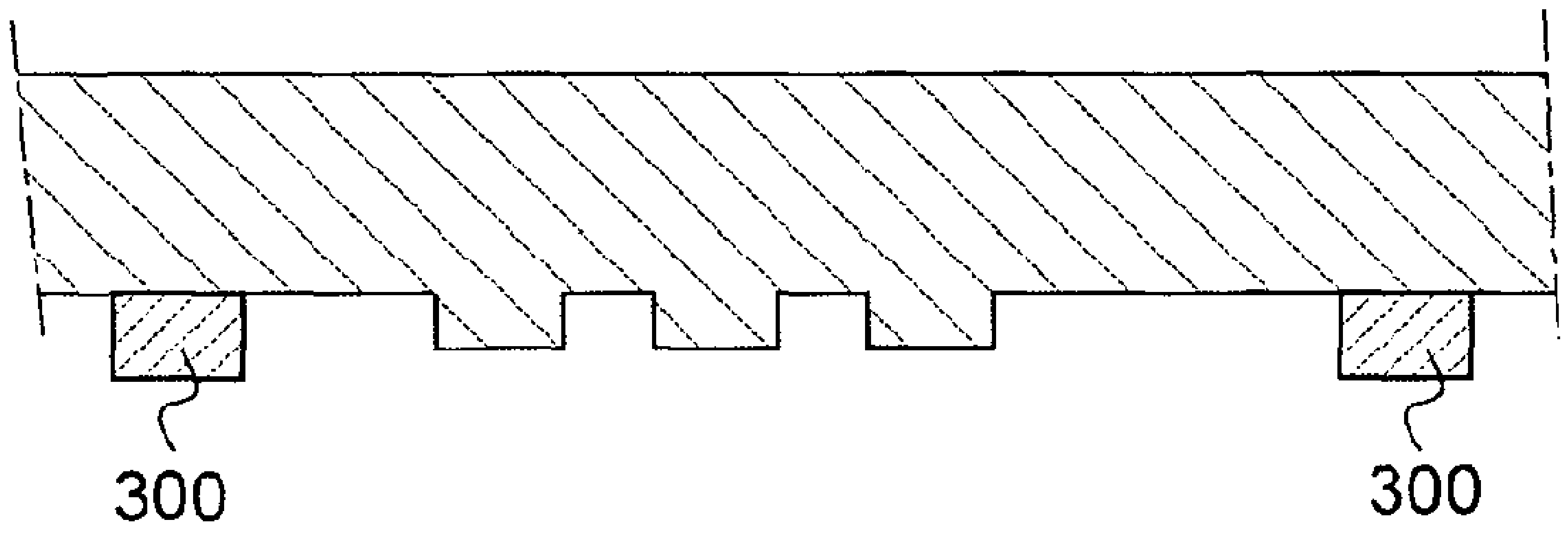


Fig.20

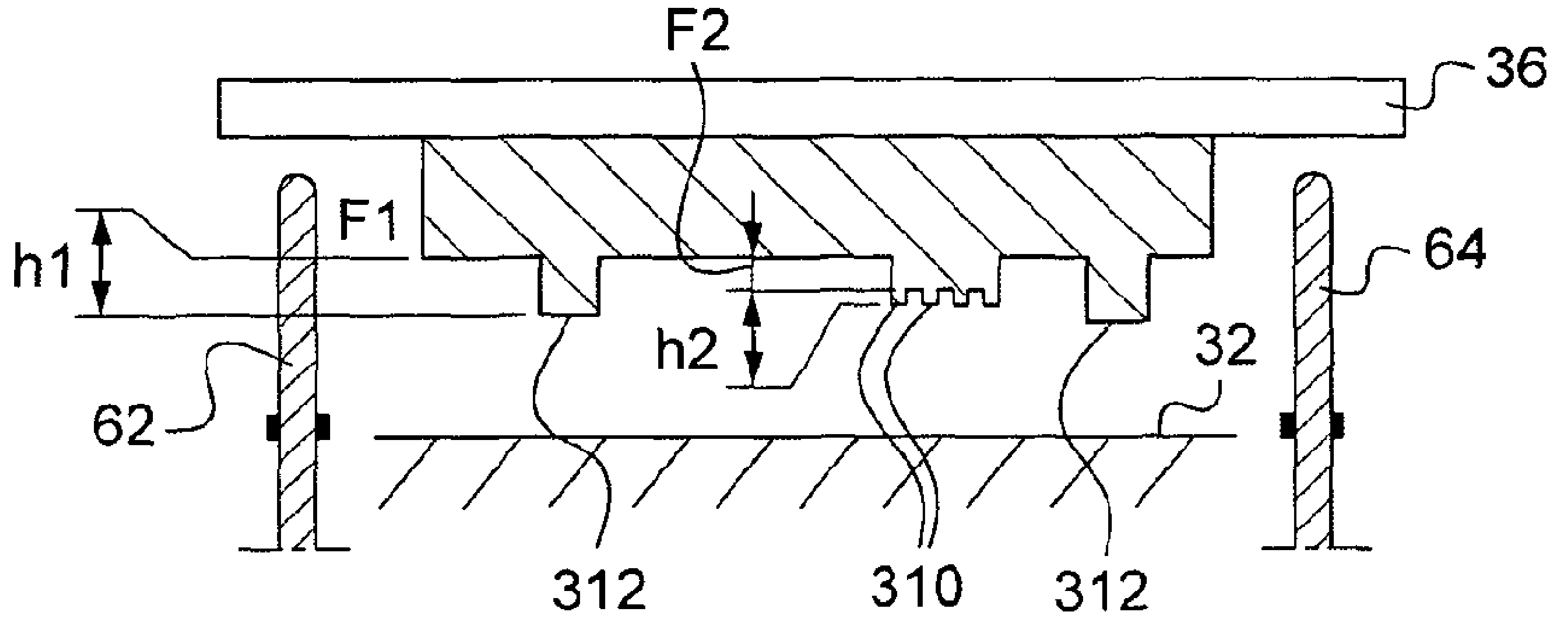


Fig.21

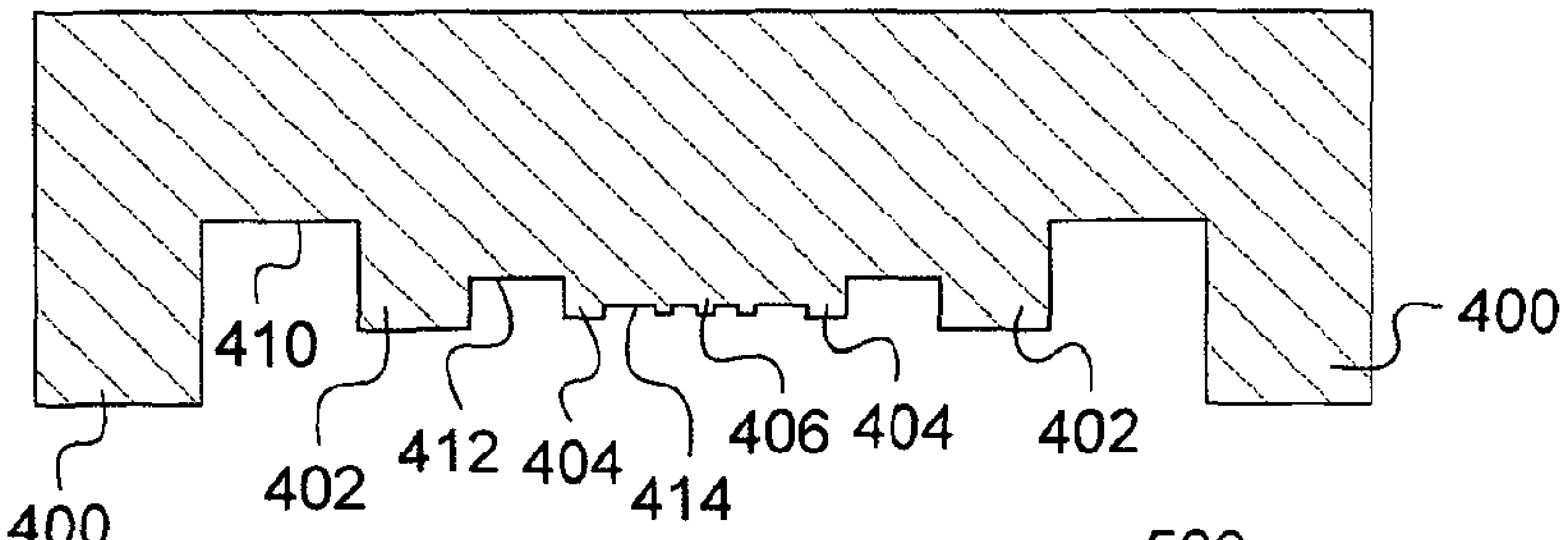
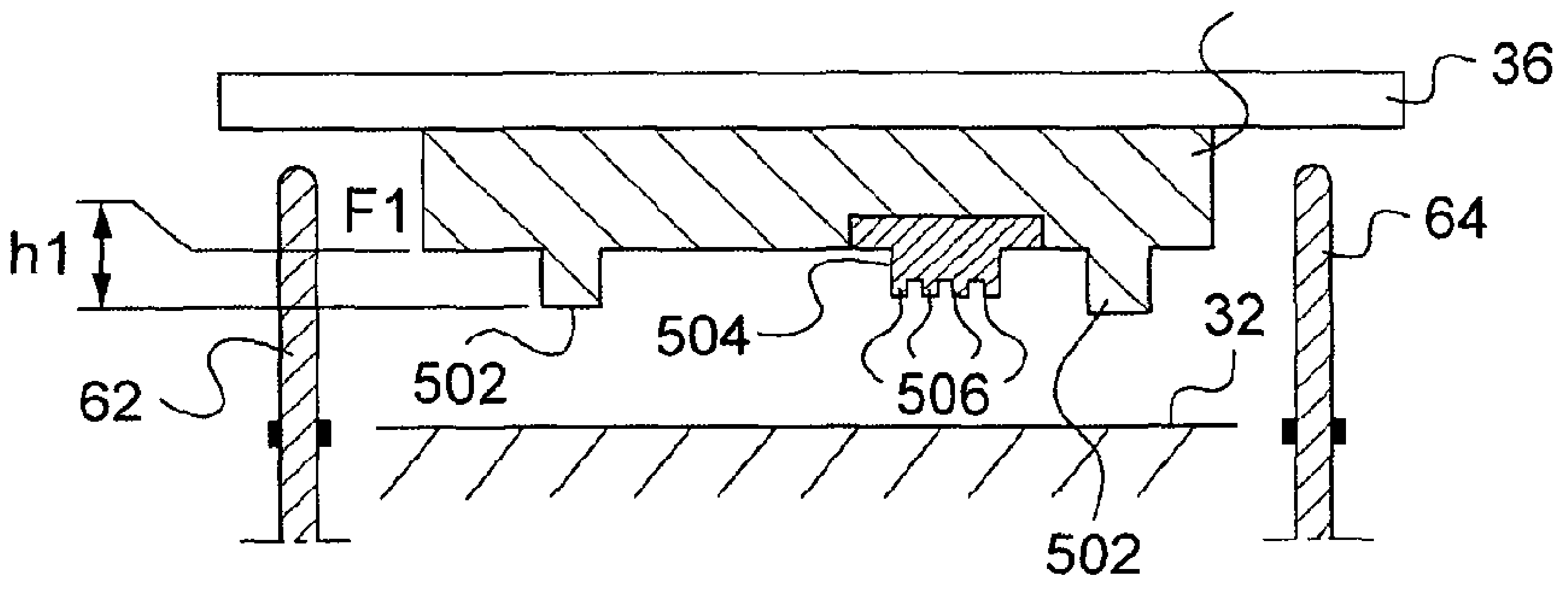


Fig.22



PAD MICROPRINTING DEVICE AND METHODS, AND PAD FOR THIS DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is the National Stage of International Application No. PCT/EP2008/063739, filed on Oct. 13, 2008, which claims the priority of French Application No. 077691, filed on Oct. 31, 2007. The contents of both applications are hereby incorporated by the reference in their entirety.

The invention pertains to a pad microprinting device, a pad for this device and pad microprinting methods.

Pad microprinting devices comprise a substrate and a pad capable of printing an imprint on one face of this substrate.

The Applicant knows pads comprising:

a layer of elastomeric material having a first flat bottom from which there protrude n successive levels of embossed patterns, classified in descending order of height h_i, where n is an integer greater than or equal to two and the index i represents the pattern level with i being equal to one for the pattern for which the height h_i is the greatest,

a first pattern level, called a conformation level, enabling the first flat bottom to be coarsely parallelized with the face of the substrate, this pattern being formed by several protrusions of a height h_1, these protrusions defining at least three non-collinear support points on said face and around the first flat bottom, the height h_1 being measured relative to this first flat bottom and in a direction perpendicular to this first flat bottom, and

an nth pattern level, called a printing level, capable of coming into contact with the face of the substrate solely after the (n−1)th pattern level has thus been put into contact with this face, to print the imprint on the face of the substrate, this pattern being formed by one or more protrusions with a height h_n projecting perpendicularly from an nth flat bottom which is the same as or is parallel to the first flat bottom and situated between the three supporting points of the first pattern level, the height h_n being included between $h_{n-1}/2$ and $0.5\times SFQR_{max}$, where $SFQR_{max}$ (Max Site Frontside least sQuare focal plane Range) is a standardized measurement of the flatness of the substrate, the height h_n of each protrusion being measured relative to the nth bottom plate and perpendicularly to this nth bottom plate.

The measurements of the flatness of the substrate such as the GBIR (Global Backside Ideal focal plane Range), $SBIR_{max}$ (Max Site Backside Ideal focal plane Range) and $SFQR_{max}$ are defined in the following standards: DIN 50441-1, SEMI MF1530 and SEMI M1. Only a brief description of these measurements is given herein. For further information the reader may refer to the text of these standards.

The GBIR or TTV (Total Thickness Variation) measurement was defined through the following relationship:

$$GBIR = d_{max} - d_{min}$$

where:

d_{max} and d_{min} are respectively the maximum and minimum thicknesses of the substrate measured relative to a plane of reference.

The GBIR measurement is shown in FIG. **1**. In this figure, the reference plane is constituted by a flat bottom **2** on which the substrate is held. The bottom **2** is represented by a line of dashes. A portion **4** of the upper surface of the substrate is also illustrated.

The SBIR or LTV measurement is a local measurement of the flatness of the substrate. For this measurement, the surface of the substrate is divided into sites. FIG. **2** represents an example of a substrate **6** whose surface is divided into 52 sites.

For each site i, the SBIR measurement is given by the following relationship:

$$SBIR_i = d_{max} - d_{min}$$

where:

d_{max} and d_{min} are respectively the maximum and minimum thicknesses of the substrate at the site i relative to a reference plane herein constituted by the bottom of the substrate.

The thicknesses d_{min} et d_{max} are represented for n sites in FIG. **3**.

The measurement $SBIR_{max}$ is given by the following relationship: $SBIR_{max} = \max[SBIR_1, SBIR_2, \ldots, SBIR_i, \ldots, SBIR_n]$.

Finally, the $SFQR_i$ (Site Frontside least sQuare focal plane Range) measurement is a local measurement on the site i of the flatness of the surface of the substrate. This measurement $SFQR_i$ is given by the following relationship:

$$SFQR_i = |x| + |y|$$

where:

|x| is the absolute value of the maximum protuberance relative to a reference plane known as a "focal plane" and

|y| is the absolute value of the depth of the greatest dip relative to the reference plane.

For example, the position of the reference plane is determined by the least error squares method to minimize the differences of the surface of the substrate relative to this plane.

To illustrate the definition of the values x and y, these values are represented for a single site i in FIG. **4**. In this figure, the reference plane is represented by a line of dashes.

The measurement $SFQR_{max}$ is given by the following relationship:

$$SFQR_{max} = \max[SFQR_1, SFQR_2, \ldots, SFQR_i, \ldots SFQR_n].$$

The term "flat bottom" is also used to define a smooth surface with no rough features and having a height greater than $h_n/10$ except for the embossed patterns which are deliberately built on this bottom.

A multi-level pad is disclosed in the U.S. Pat. No. 5,817,242 (see FIG. **8**). In this document, the pad comprises solely one first conformation pattern level and one printing pattern level. The protrusions of the first pattern level are made out of elastomeric material and more specifically PDMS (poly(dimethylsiloxane)). However, the printing pattern is made out of a much harder material, i.e PMMA (poly(methyl methacrylate)). The Young's modulus of PMMA ranges from 1.8 to 3.1 GPa. The use of PMMA prevents the crushing of the protrusions of the printing pattern during pad printing. Indeed, excessive crushing of the protrusions of the printing pattern leads to an illegible imprint.

However, the hardness of the protrusions of the printing pattern introduces new problems. For example, this pad is extremely sensitive a local defect of flatness of the substrate such as a bump. An example of this situation is shown in FIG. **5**. In FIG. **5**, a substrate **10** has a bump **12**. A few PMMA protrusions of the printing pattern of the pad are shown. As illustrated in this figure, because of the hardness of PMMA, the bump **12** of the substrate prevents a large number of protrusions from coming into contact with the face of the substrate. Thus, the quality of the print made with this pad is highly sensitive to the presence of local defects of flatness, especially submicrometric defects.

The invention is aimed at overcoming this drawback by proposing a pad microprinting device that is less sensitive to local defects of flatness of the substrate. An object of the invention therefore is a pad microprinting device in which:

- the printing pattern is made out of elastomeric having a Young's modulus between 0.10 and 100 MPa, an
- the device has a stop mechanism capable of keeping an incompressible space of a thickness D_n between the nth flat bottom and the face of the substrate when the pad is thrust against the face of the substrate to print off the imprint, the thickness D_n being between $h_n/2$ and h_n+100 nm. Using the pad mentioned here above, as illustrated in FIG. **6**, when the printing pattern is applied against the same bump **12** as the one described with reference to FIG. **5**, the printing pattern, which is made of elastomeric instead of PMMA gets locally deformed, thus enabling the application to the substrate of the protrusions **20** which are to the right and to the left of the bump **12**. In FIG. **6**, only the printing pattern is shown. The crushing of the printing pattern is prevented through the stop mechanism makes it possible to control the load exerted by the pad during the contact with very high resolution in preventing this pattern from being crushed over more than half of its height h_n. Thus, the pad microprinting device described here is less sensitive to local defects of flatness of the substrate. Furthermore, this pad is used to make submicrometric prints in a more controlled manner than with the pad described in the U.S. Pat. No. 5,817,242 which relies solely on the rigidity of the printing pattern to prevent it from being crushed during a microprinting.

In practice, it is particularly advantageous to use multilevel pads by adding levels of conformation patterns supplementary the level n printing pattern at heights of over h_i with $i=1$ to $n-1$. Indeed, as explained further below, these supplementary patterns facilitate the setting of the microprinting device and the implementing of the method.

The embodiments of this microprinting device may comprise one or more of the following characteristics:

- The stop mechanism is also capable of stopping the pad in a position where the space of thickness D_i separates firstly the face of the substrate and secondly an ith flat bottom which is the same as or is parallel to the first flat bottom, from which there protrude the level i protrusions of a height h_i, the thickness D_i being included between $h_i/2$ and h_i and i being included between 1 and $n-1$.
- The stop mechanism comprises at least three stops having heights adjustable independently of one another and being placed along at least two non-collinear axes so that the adjusting of the heights of each stop modifies the tilt of the entire pad relative to the face of the substrate.
- The device comprises:
  - a difference sensor capable of detecting or measuring a variable representing the parallelism of an ith flat bottom which is the same as or is parallel to the first flat bottom and from which there protrude protrusions of height h_i of the level i, and
  - an electronic computer capable of automatically adjusting the height of the stops as a function of this variable detected or measured by the sensor to parallelize the ith flat bottom with the face of the substrate.
- The device comprises:
  - A pad-holder on one face of which is fixed the pad or a substrate-holder on one face of which is fixed the substrate, the pad-holder and the substrate-holder having a Young's modulus of over 1 GPa,
  - at least one stop controllable taking support firstly on said face of the pad-holder and secondly on the pad or firstly on said face of the substrate and, secondly, on the substrate-holder, this stop being capable, at the level of the supporting points, of locally deforming the curvature of the pad or of the substrate, with an adjustable amplitude, in a direction parallel to the direction of compression of the pad on the substrate,
  - a sensor of defects of flatness of the face of the substrate on which the imprint has to be printed or of defects of the face of the pad bearing the printing pattern, and
  - a computer capable of controlling the controllable stop as a function of the measurements of the flatness defect sensor to adjust the amplitude of the local deformation as a function of the flatness defect.

These embodiments of the microprinting device furthermore have the following advantages:

- being able to stop the pad in a position where only one or more conformation patterns are in contact with the substrate allows the pad time to get deformed before printing the imprint on the face of the substrate by means of the printing pattern,
- the presence of at least three motor-driven stops having heights adjustable independently of one another makes it possible to adjust the overall tilt of the pad relative to the face of the substrate,
- the use of a difference sensor and the automatic setting of the height of the stops as a function of the data transmitted by this sensor enables the automatic setting of the tilt of the pad relative to the face of the substrate, and
- the use of adjustable stops between the pad-holder and the pad or between the substrate-holder and the substrate makes it possible to compensate for the local defects of flatness of the substrate or of the pad.

An object of the invention is also a pad designed to be implemented in the above microprinting device.

The embodiments of this pad may include one or more of the following characteristics:

- The pad comprises at least one intermediate level i of conformation patterns used to achieve a more precise parallelization of the nth flat bottom with the face of the substrate on which the imprint must be printed, each intermediate level i being formed by several protrusions of a height h_i above the standardized SBIR (Site Backside Ideal focal plane Range) measurement of flatness of the substrate and below $h_{i-1}/2$ where h_{i-1} is the height of the protrusions of level $i-1$ just greater than the conformation pattern, these protrusions defining at least three non-collinear supporting points arranged around the nth flat bottom.
- The pad has at least one air escape channel linking a space, situated between the protrusions of each pattern level, to the exterior of the pad in order to enable air likely to be imprisoned between the substrate and the pad to escape out of the pad when the pad is thrust against the face of the substrate.
- the height h_n is smaller than or equal to 100 micrometers and preferably smaller than or equal to 1 micrometer or 0.3 micrometers.

The embodiments of this pad furthermore have the following advantages:

The use of an intermediate level of conformation pattern improves the parallelism between the (n−1)th flat bottom and the face of the substrate, and this ultimately improves the sharpness of the imprint,

the presence of escape channels prevents the trapping of air bubbles between the pad and the substrate, thus improving the quality of the imprint,

printing patterns whose height h_n is smaller than one micrometer enable the making of an imprint comprising patterns of which the smallest width is smaller than one micrometer.

An object of the invention is also a method for contactless printing of an imprint on the face of a substrate by pad microprinting using the above device, this method comprising:

the maintaining of a incompressible space of thickness D_n between the nth flat bottom and the face of the substrate when the pad is thrust against the face of the substrate to print the imprint, the thickness D_n being included between h_n+1 nm and h_n+100 nm to enable an ink deposited on the end of each protrusion of the printing pattern to go through this incompressible space of thickness D_n, then

the moving of the pad away from the face of the substrate without the protrusion or protrusions of the printing pattern being placed in direct contact with the face of the substrate. In the above method, since the thickness D_n ranges from h_n+1 nm to h_n+100 nm, the printing pattern is kept above the face of the substrate at a distance of between 1 nm and 100 nm. This distance is small enough to enable the ink that covers the printing pattern to cross this space of a thickness D_n in order to form the imprint on the face of the substrate. However, in this embodiment, given that the protrusions of the printing pattern do not come into direct contact with the face of the substrate, this face is not deformed, thus improving the quality of the print obtained. An object of the invention is also a method for printing an imprint on the face of a substrate by pad microprinting using the above pad microprinting device characterized in that the method comprises:

adjusting the stop mechanism to stop the compression of the pad on the substrate in a first position where one of the conformation pattern levels is directly supported on the face of the substrate while the nth flat bottom is separated from the face of the substrate by a distance strictly greater than h_n+100 nm, then

adjusting the stop mechanism so that the compression of the pad on the substrate can continue until a second position of the nth flat bottom is at a distance from the face of the substrate equal to the incompressible space of thickness D_n.

The embodiments of this method can include one or more of the following characteristics:

Before the protrusions of a pattern level i are brought into contact, the method comprises:

holding level i−1 protrusions in a supported position on the face of the substrate and, at the same time

adjusting the height of each motor-driven stop of the stop mechanism to parallelize the ith flat bottom, demarcated by the I level pattern protrusions, with the face of the substrate.

The method comprises:

detecting or measuring a variable representing the parallelism of an ith flat bottom which is the same as or is parallel to the first flat bottom and from which there protrude protrusions of height h_i of the level i, and

adjusting the height of each motor-driven stop as a function of the detected or measured variable in order to parallelize the ith flat bottom with the face of the substrate.

These embodiments of the pad microprinting method furthermore have the following advantages:

stopping the motion of the pad when only one part of the conformation pattern levels is directly supported on the face of the substrate allows time for the pad to get deformed before carrying out an additional crushing of this pad, and this ultimately improves the quality of the imprint,

adjusting the stops so as to improve the parallelism between a pattern level and the face of the substrate before carrying out an additional crushing of the pad improves the quality of the imprint obtained,

adjusting the height of each stop as a function of the detection of measurement of the differences between the protrusions and the face of the substrate automatically adjusts the height of the stops to adjust the parallelism between the pad and the face of the substrate before carrying out an additional crushing of this pad.

The invention will be understood more clearly from the following description, purely by way of a non-restrictive example and made with reference to the appended drawings of which:

FIG. **1** is a schematic illustration of the GBIR measurement,

FIG. **2** is a schematic illustration of the sub-division of the surface of a substrate into several sites,

FIG. **3** is a schematic illustration of the $SBIR_i$ measurement,

FIG. **4** is a schematic illustration of the $SFQR_i$ measurement on a particular site of the substrate,

FIG. **5** is a schematic and partial illustration of the of a prior art pad,

FIG. **6** is a schematic and partial illustration of a printing pattern made out of elastomeric material

FIG. **7** is a schematic illustration of the structure of a pad microprinting device,

FIG. **8** is a more detailed **3**D illustration of a hinge system used in the device of FIG. **7**,

FIG. **9** is a schematic illustration of a difference sensor used in the device of FIG. **7**,

FIG. **10** is a top view of the positioning of the motor-driven stops used in the device of FIG. **7**,

FIG. **11** is a schematic illustration of a vertical section of a multi-level pad used in the device of FIG. **7**,

FIG. **12** is a flowchart of a method of pad microprinting using the device of FIG. **7**,

FIGS. **13** to **18** are schematic illustrations of certain particular steps of the method of FIG. **12**,

FIGS. **19** to **22** represent other different possible embodiments of a multi-level pad that can be used in the device of FIG. **7**,

FIG. **23** represents a flowchart of another embodiment of the pad microprinting method of FIG. **13**, and

FIG. **24** is a schematic view in section of a detail of a variant of the device FIG. **7**.

In these figures, the same references are used to designate the same elements.

Here below in this description, the characteristics and functions well known to those skilled in the art shall not be described in detail.

FIG. **7** shows a pad microprinting device **30**. The device **30** described here is designed for the printing, on a substrate **32**, of an imprint whose patterns must have widths of less than 100 micrometers. Typically, the machine described here can be used to obtain patterns whose width is below one micrometer or 500 nm or even below 50 nm. At these scales, the applications concern, for example and non-restrictively: micronanotechnology, microelectronics and microphotonics. However this device can also be used in nano-biotechnology microapplications, surface chemistry and microfluidic chemistry which require patterns of up to 100 μm.

The device **30** is placed on a horizontal plane X,Y and extends upwards along a vertical direction Z.

The device **30** has a pad **34** made of elastomeric material. The pad **34** is described in greater detail with reference to FIG. **11**.

This pad **34** is fixed without any degree of freedom to a pad-holder **36** made out of rigid materials. Here below, the term "rigid" shall be applied to a material for which the Young's modulus is greater than 1 GPa and preferably greater than 60 GPa. For example, the pad-holder **36** is made of aluminum or steel. The pad-holder **36** is a rectangular plate extending essentially in parallel to the plane X,Y. The pad-holder **36** is fixed on a sliding rigid support or trolley **40** by means of a hinge **42**. The hinge **42** is described in greater detail with reference to FIG. **8**.

The trolley **40** is mounted so as to be sliding solely in the direction Z. To this end, for example, the movements of the trolley **40** are guided by vertical sliders **44** and **46** which are precision vertical sliders. The vertical sliders **44** and **46** are fixed to a rigid frame **40** without any degree of freedom. The frame **48** rests on a horizontal surface.

The trolley **40** is moved upwards along the direction Z by a return mechanism herein formed by example by two return springs **50** and **52**.

The downward movement of the trolley **40** along the direction Z is controlled by example by a controllable pneumatic jack **54**. This jack **54** is capable of moving the trolley **40** against the pull-back force of the springs **50** and **52** to crush or compress the pad **34** against the substrate **32**. Should the pad **34** be made out of a material transparent to visible light, a sensor **60** of difference between the pad **34** and the substrate **32** is installed in the trolley **40**. An example of such a sensor **60** is described in greater detail with reference to FIG. **9**.

The device **30** also has a stop mechanism formed herein by three motor-driven stops **62** to **64** extending along the direction Z. One end of each of the stops is fixed without any degree of freedom to a shoulder **66** of the frame **48**. The shoulder or shoulders **66** are distributed in a horizontal plane. The opposite end of these stops **62** to **64** can come into a position where it is directly supported on the pad-holder **36** when this pad-holder is shifted downwards. The height of each of these stops is adjustable. To this end, each of these stops has a controllable activator used to adjust the height of each of the stops with a resolution of motion in the direction Z that is at least below $h_n/2$. Typically, its resolution is below $h_n/5$ and preferably below $h_n/10$. For example, the resolution of the motion of the stops in the direction Z is between 1 nm to 10 nm. In this case, the actuators are piezoelectric actuators.

This stop mechanism is used to very finely adjust the load or force exerted by the jack **54** on the pad **34**. Indeed, in a state of equilibrium, the force exerted on the jack is fixed by the height of the stop **62** to **64**. The force exerted by the jack is distributed between a first component on the pad **34**, independent of the thrust exerted by the jack **54** on the pad-holder **36** and a second variable component on the stops **62-64**. The stops **62-64** exert a reaction which is automatically added to the reaction of the pad **34** to balance the thrust of the jack **54** and also compensating for any variation or fluctuation of this thrust.

This principal considerably reduces the load exerted by the pad during contact between the pad and the substrate. Indeed, the load on the pad **34** is no longer dependent on the overall force exerted by the jack **54** on the pad-holder **36** but depends only on the height of the stops **62-64**. It can then be adjusted with very high resolution, defined by the resolution of the setting of the movement of the stops. Thus, the invention removes the need to adjust the load exerted by the jack **54** with high resolution. On the contrary, it is possible to permanently exert high thrust, for example a thrust of over 1N, on the pad-holder **36**, while the load is adjusted by piezoelectric actuators. For example, with a jack exerting a load of 1N, it is possible to put a 50×50 mm^2 pad **34** made of PMDS with heights h_1, h_2 and h_3 respectively equal to 10 μm, 1 μm and 100 nm in using three piezoelectric actuators with a travel of 20 μm and a resolution of 10 nm. The heights h_1, h_2 and h_3 are defined in greater detail with reference to FIG. **11**.

The substrate **32** is mounted without any degree of freedom on a horizontal substrate-holder **70**. The substrate-holder **70** can be moved in translation in the directions X and Y and rotationally about a vertical axis by the controllable actuators **72** and **75**.

Finally, the device **30** includes an programmable electronic computer **80** capable of controlling the jack **54** as well as the different actuators of the device **30**, and especially the actuators of the stops **62** to **64**. The computer **80** is capable of executing instructions recorded on an information-recording medium. To this end, the computer **80** is connected to a memory **82** comprising the instructions needed to execute the method of FIG. **12**.

FIG. **8** provides a more detailed representation of an example of an embodiment of the hinge **42**. This hinge **42** enables the pad-holder **38** to pivot about any axis whatsoever contained in the plane of this pad-holder **36**. Furthermore, this hinge **42** can stretch or be shortened like a spring in the direction Z. Here, by way of an example, this hinge **42** is formed by two rings **84** and **86** each made of an elastically deformable material. For example, the rings **84** and **86** are made out of metal. Each ring extends in a respective vertical plane. More specifically, the rings **84** and **86** extend respectively in orthogonal vertical planes. The rings **84** and **86** are fixed to each other without any degree of freedom.

FIG. **9** provides a more detailed view of an example of a difference sensor **60**. The sensor is designed to work with a pad made out of elastomeric material transparent to visible light and showing low auto-fluorescence. For example, the material used to make the pad **34** is Sylgard 184® commercially distributed by the firm Dow Corning. The pad **34** has protrusions. The sensor **60**, for each protrusion, measures the smallest difference between its end and the face of the substrate. These measurements therefore represent the parallelism between the flat bottom situated between these protrusions and the front face of the substrate **32**. This sensor therefore makes possible especially to detect the contact of a protrusion with the substrate **32**. Here, the end of these protrusions is covered by fluorescent material such as for example the CY3 fluorophore.

The sensor **60** has a visible light source **90**. The visible light sent out by this source **90** is focused and concentrated by means of the different lenses **92**, **94**, then crosses a diaphragm **96** and is then collimated by a lens **98**. The collimated light finally crosses a filter **100** and is then reflected by a semi-transparent mirror **102** towards the pad **34**. The fluorescent light generated by the CY3 fluorophore crosses an objective

104 with high magnification focused on a point of the substrate and then a filter **105** capable of letting through solely light generated by the CY3 fluorophore. Indeed, the mirror **102** has a surface treatment which reflects the light emitted in the bandwidth of the filter **100** and lets through light emitted the bandwidth of the filter **105**. The two bandwidths are distinct.

After the light generated by the CY3 fluorophore has been excited by the visible light, it crosses the objective **104**, the mirror **102** and then the filter **105** and reaches an objective **106** which concentrates this fluorescent light on a photomultiplier **108**. The closer a protrusion coated with CY3 fluorophore is to the face of the substrate, the greater is the increase in the light intensity picked up by the photomultiplier **108**. This intensity reaches a maximum when a CY3 fluorophore coated protrusion comes into contact with a substrate **32**. Thus, the difference between the end of a protrusion is measured, and the contact between this protrusion and the substrate **32** is detected on the basis of the light intensity received by the photomultiplier. The light intensity measured is also proportional to the area of the surface of the protrusion in contact with the substrate **32**. This sensor **60** therefore also enables measurement or estimation of the area of the surface of this protrusion which is contact with a substrate **32**.

Other difference sensors are described at the end of this description.

FIG. **10** is a top view of a substrate **32**. Here, the substrate **32** is a rectangular plate, for example made of silicon. The stops **62** to **64** are arranged in a circle, the centre of which is situated within the rim of the substrate **32**. For example, the center of the circle on which the stops **62** to **64** are situated is the same as the center of the substrate **32**. Here, the stops **62** to **64** are laid out at the same distance from one another.

FIG. **11** provides a more detailed view of a portion in a section along a plane X, Y of the pad **34**. Typically, the portion shown is repeated several times in the direction X.

The pad **34** is made here out of a homogenous elastomeric material, the Young's modulus of which is between 0.1 MPa and 100 MPa. The term "homogenous elastomeric material" designates a material for which the Young's modulus is constant in the directions X, Y and Z. Preferably, the pad **34** is made out of an elastomeric material with its Young's modulus between 1 and 10 Mpa. For example in this case, the pad **34** is made out of a PDMS (poly(dimethylsiloxane)). More specifically, the pad **34** is made out of one of the following PDMS materials:

Sylgard 184® for which the Young's modulus is equal to 1.8 MPa,
PDM-h for which the Young's modulus is equal to 9 MPa,
Rhodorsil RTV 3255 by the firm Rhodia equal to 4.4 MPa, and
Photocurable PDM-hυ for which the Young's modulus is equal to 3.4 MPa after photopolymerization.

For further details on PDM-h, the reader may refer to one of the following articles:

H. Schmid, B. Michel, Siloxane Polymers for High-Resolution, High-Accuracy Soft Lithography, Macromolecules 2000, 33, 3042-3049

Teri W. Odom, J. Christopher Love, Daniel B. Wolfe, Kateri E. Paul, and George M. Whitesides, Improved Pattern Transfer in Soft Lithography Using Composite Stamps, Langmuir, 18 (13), 5314-5320, 2002

The pad **34** is a multi-level pad comprising n levels of embossed patterns where n is an integer greater than or equal to two.

The pad **34** has a PDMS layer **120** having a flat bottom **122** pointing towards the substrate **32**. This layer has a thickness between 0.1 micrometers to 10 mm, preferably between 1 μm and 1 mm.

N embossed pattern levels protrude from the layer **122** where n is an integer greater than two. These levels are classified by order of size going from the biggest to the smallest. Each level is formed by protrusions all having the same height h_i, where the index i designates the pattern level, the value "1" of the index i corresponding to the greatest height. The protrusions of each level i where i is strictly smaller than n demarcate an ith flat bottom placed between these protrusions. The i+1 level protrusions extend perpendicularly from the ith flat bottom. The level n protrusion or protrusions protrude from an nth flat bottom. In the case of the pad **34**, the n flat bottoms are the same as one another. The height h_{i-1} is measured relative to the ith flat bottom and perpendicularly to this flat bottom. The height h_{i-1} is strictly smaller than the height h_i. Preferably, the height $_{-1}$ is at least twice as small as the height h_i or at least ten times smaller than the height h_i.

The intermediate levels i with 1<i<n is used to enhance the precision, level by level, of the alignment of the pad with the substrate as well as to adjust it with respect to the parallelism of the level considered with the substrate. Using the principal of stops, it is possible (i) to place all the patterns of the same height in contact simultaneously whether the pattern is isolated on the surface of the pad or whether, on the contrary, it is a major part of the surface of the pad and (ii) to crush all the patterns of a same height simultaneously.

Here, all the protrusions are of the same material as the layer **120** and therefore form a single block with this layer.

Each protrusion has substantially vertical side faces which terminate at a flat end designed to take support on the substrate **32**.

The horizontal section, i.e. in the plane XY, of each protrusion may be any unspecified section. For example, this section may have the shape of a cross, a circle, a square or again a rectangle. When the section is a highly elongated rectangle, the protrusion forms a ridge. The protrusions designed to deposit ink on the face of the substrate **32** have a shape factor between 0.2 and 2. The shape factor of a protrusion is defined by the ratio between its height h_i and its smallest width L. Preferably, the shape factor is equal to one.

Each protrusion of a height h_i is surrounded by an exclusion zone of a width Z. No lower-level pattern should be located in this exclusion zone. Indeed, this exclusion zone is designed to absorb deformations of the protrusion when it is strongly crushed against the face of the substrate **32**. The smallest width Z_i of the exclusion zone is inversely proportional to the Young's modulus of the elastomeric forming the protrusion and is proportional to the compression height. The compression height of a protrusion is equal to the difference between its height h_i when it is not crushed against the substrate and the smallest height attained by this protrusion during pad printing.

For example, a pad with two levels, of which the Young's modulus is equal to 6 MPa, and with patterns of heights $h_1=20$ μm and $h_2=2$ μm, the width Z_i is about 15 h_1 giving 300 μm. In this case, the compression height of the protrusions of the level **1** is equal to h_1-h_2.

Thus, generally, the smallest width of the exclusion zone Z_i is greater than 15 h_i and preferably greater than 25 h_i.

Thereafter, this proportion between the width Z_i and the height h_i was not kept in the FIGS. **5** to **24** to simplify these illustrations. The n−1 first levels are called "conformation patterns" because they enable the nth flat bottom to be parallelized with varying degrees of precision with the surface of the substrate. The nth pattern level is called a "printing pattern" because it is used to make the imprint on the substrate **32**.

FIG. **11** represents the pad **34** in the particular case where n is equal to three.

The first level is formed by protrusions **124** with a height h_1. The two protrusions **124** which can be seen in FIG. **11** demarcate a first flat bottom **122**A extending between these two protrusions **124**. The flat bottom **122**A is herein simply a particular zone of the flat bottom **122**.

The height h_1 is the greatest of the heights h_i. This first level is used to parallelize the bottom **122**A with the face of the substrate **32**. To this end, the protrusions **124** form at least three supporting points on the face of the substrate **32**. These supporting points are distributed on non-collinear axes and surround the bottom **122**A.

Here, the horizontal section of the protrusions **124** is rectangular. The small side of this section extends in the direction X while the big side extends in the direction Y. The big side is for example three times longer than the small side. Thus, the supporting points are distributed along two orthogonal axes respectively, parallel to the directions X and Y. More specifically, each protrusion **124** forms two supporting points aligned along the axis parallel to the direction Y.

The vertical faces of the two protrusions **124** and the bottom **122**A form a channel opening out on to the periphery of the pad **124**. Thus, this channel prevents air from being trapped between the protrusions **124** when these protrusions are crushed against the substrate **32**. The height h_1 is at least greater than half the measured value GBIR of the flatness of the substrate **32** and preferably greater and even several times greater than this measured value GBIR.

Here, the protrusions **124** are also used to align the pad **34** relative to the substrate **32**. The position of the protrusions **124** in the horizontal plane can therefore be measured by means of a camera or any other means. To this end, in order that the position of the protrusions **124** can be measured by means of a camera, their smallest width L_1 is chosen to be at least greater than 1 μm.

The second level of the embossed pattern is formed by protrusions **130** with a height h_2. This is an intermediate conformation pattern used to obtain a more precise parallelization of a flat bottom **122**B with the face of the substrate **32**. For example, the horizontal section of the protrusions **130** is rectangular. The smallest side and the greatest side of this section extend so as to be parallel respectively to the directions X and Y.

The vertical faces of the two protrusions **130** and the bottom **122**B also form a channel opening out on to the periphery of the pad **34**. Thus, this channel prevents air from being trapped between the protrusions **130** when these protrusions are crushed against the substrate **32**.

The smallest horizontal width of the protrusions **130** is denoted as L_2. Similarly to the first level, the protrusions **130** of the second conformation level form at least three supporting points on the face of the substrate **32** distributed on orthogonal axes parallel to the directions X and Y. These supporting points surround the second flat bottom **122**B. These second-level protrusions **130** provide for a more precise parallelization of the bottom **122**B with the face of the substrate **32**.

The height h_2 should be greater than half the measured value $SBIR_{max}$ of the flatness of the substrate **32** and, preferably, greater or several times greater than this measured value. For the measurement of $SBIR_{max}$ it is assumed that the same imprint is printed by means of the pad **34** in several different printing zones of the face of the substrate **32**. Each side then corresponds to a respective printing zone.

The third level is formed by protrusions **134** of a height h_3 protruding directly from the bottom **122**B. The third flat bottom can thus be taken for the second flat bottom. The protrusions **134** are designed to print the imprint on the face **32**. Here, the horizontal section of these protrusions **134**, like that of the protrusions **130**, is chosen to form an air escape channel with the bottom **122**B. The height h_3 is greater than 0.5 times the measured value $SFQR_{max}$ of the flatness of the substrate **32**. Preferably the height h_3 is at least greater than the measured value $SFQR_{max}$ of the flatness of the substrate **32**. For the measured value $SFQR_{max}$, the sites taken into account are the same as in the case of the measured value $SBIR_{max}$. Here, the smallest width L_3 of the protrusions **134** is equal to the height h_3. The horizontal section of the protrusions **134** is for example rectangular and the greatest side of this section extends in the direction Y.

By way of an illustration, to make an imprint for which the smallest detail has a width of 1 micrometer, the heights h_1 to h_3 are the following: h_1=50 μm, h_2=10 μm and h_3=1 μm.

To make an imprint for which the width of the smallest detail is equal to 10 nm, the heights h_1 to h_3 are the following: h_1=1 000 nm, h_2=100 nm and h_3=10 nm.

The working of the device **30** shall now be described in greater detail with reference to the method of FIG. **12**.

Initially, a phase **150** for manufacturing the pad **34** is performed. For example, this phase **150** starts with a step **152** for providing a silicon block **154** (FIG. **13**). Typically, the flatness of the block **154** is at least equal to that of the substrate **32** and preferably better than that of the substrate **32**.

Then, in a step **156**, a negative etching is made of the conformation and printing patterns in the upper face of the block **150**. For example, these patterns are etched by RIE (Reactive Ion Etching) because this method gives a greater shape factor, i.e. a shape factor greater than or equal to 1.5. Other methods such as the DRIE (Deep Reactive Ion Etching) or FIB (Focus Ion Beam) methods can also be used to etch conformation and printing patterns negatively in the block **154**. At the end of the step **156** a mold or master model is obtained (see FIG. **14**).

Then, at a step **158**, the block **154** thus etched is used as a mold or master model to make the pad **34**. For example, in this case, liquid PDMS is poured into this mold (see FIG. **15**). Then, after polymerization, the black made of PDMS material is separated from the block **134** in order to obtain the pad **34**. Advantageously, the external surface of the pad **134** can be modified with anti-adhesive treatment to facilitate the demolding.

Once the pad is made, it is inked at a step **160**. Here, only the printing pattern is inked. For example, the inking is done by spraying ink on to the printing pattern or by ink-drop burst under vacuum or by any other appropriate method.

The ink is for example thiol, OTS (octadecyltrichlorosilane), dendrimers or biomolecules such as DNA, peptides or cells to be deposited on the substrate **32**.

After the pad **34** has been inked, it is aligned in a step **162** along the axes X, Y and Z with the substrate **32**. For example, at the step **162**, the position along the axes X, Y and Z of the protrusions **124** is measured. Then, the actuators **72** and **74** are controlled according to these measurements by the computer **80** to align at least three of these protrusions **124** with the targets carried either by the substrate **32** or by the substrate-holder **70**.

At a step **164**, the jack **54** is controlled so as to shift the pad **34** along the direction Z until the pad-holder **36** is supported on the three stops **62** to **64**. Initially, the height of the three stops **62** to **64** is adjusted so that none of the protrusions of the pad **34** is in contact with the substrate **32**. An example of an initial position is illustrated in FIG. **16**.

Then, a step **166** begins for calibrating the height of the stops to achieve a coarse parallelization of the bottom **122**A with the face of the substrate **32**.

During all the following steps and operations for adjusting the height of the stops **62** to **64**, the pad-holder **36** is held so as to be supported on the stops **62** to **64** by the jack **54**.

For example, the step **166** starts with an operation **170** for adjusting the height of the stops **62** to **64** to bring the pad into a first position where it is potentially flush with the face of the substrate **32**. Then, the pad **34** is held still in this position in keeping the height of the stops **62** to **64** unchanged. In a subsequent operation **172**, the sensor **60** is put into operation to enumerate the number of pads of the first level currently in contact with the upper face of the substrate **32** and to measure the area of the surfaces of the pads in contact with the substrate **32**.

In an operation **174**, the sum of the areas measured is compared with the sum of the areas measured is compared with the sum of the areas of the ends of the protrusions **124**. If the sum of the areas measured represents more than 10% of the sum of the areas of the ends of the protrusions **124**, then the method returns to the operation **170** where a new first position of being potentially flush is set by means of the stops **62** to **64**. Indeed, in this case, the parallelism between the pad **34** and the substrate **32** is considered to be not good enough.

If not, in an operation **176**, the computer **80** activates a reduction of the heights of the stops **62** to **64** that is simultaneous and at the same speed so that they go from the first determined flush position in the operations **170** to **174**, to a first position of contact of the protrusions of the first level with the substrate **32**. The first contact position is such that the thickness D_1 of the space between the bottom **122**A and the face of the substrate **32** in this position is greater than $h_1/2$ and smaller than h_1. Preferably, the thickness D_1 ranges from $h_1/2$ to $9\ h_1/10$. Indeed, in order to obtain a proper contact between a protrusion and the substrate, the height of the protrusion should preferably be reduced by $h_1/10$ when it is in contact with the face of the substrate. Typically, at the operation **176**, the height of each of the stops is lowered by a travel distance c_1 greater than $h_1/10$ and in any case greater than twice the measured value GBIR of the flatness of the substrate. Then, in an operation **178**, using the sensor **60**, a measurement is made again of the number of protrusions **124** in contact with the substrate **32** and the area of these protrusions in contact with the substrate **32**.

In an operation **180**, the sum of the areas measured is compared with the sum of the areas of the ends of the protrusions **124**. If the sum of the areas measured is smaller than 80% of the sum of the total areas of the ends of the protrusions **124**, then the method returns to the operation **170**. Indeed, this means that the parallelism between the pad and the substrate is not good enough. If not, an operation **182** is carried out for memorizing the last flush and contact positions found. In an operation **182**, the pad **34** is kept in the first contact position for a time between 0.5 s and 10 s.

An example of an incorrect contact position calling for a return to the operation **170** is show in dashes in FIG. **17**. In FIG. **17**, a solid line also illustrates an example of a correct contact position.

At the end of the operation **182**, a step **190** is performed for adjusting the parallelism of the bottom **122**B with the face of the substrate **32**. To this end, at the step **190**, the protrusions **130** of the second level of conformation patterns is used.

The step **190** starts with an operation **192** for lowering the height of the stops **62** to **64** to a second potentially flush position in which the protrusions **124** are crushed against the face of the substrate **32** while the protrusions **130** are close to this face but do not touch it directly.

Then, operations **194** to **204** are performed. These operations **194** to **204** are respectively identical to the operations **172** to **182** except for the fact that the work is done with the protrusions **130** instead of the protrusions **124**.

An example of a second accurate flush position is shown in FIG. **18**.

At the end of the step **190**, the downward movement of the pad **34** is stopped in a second contact position where the space of thickness D_2 of the space between the bottom **122**B and the face before the substrate **32** is included between $h_2/2$ and $9\ h_2/10$. The pad **34** is kept in this second position of contact for 0.5 s to 10 s.

Thus, before transferring the n-ranked pattern, the pad is put into contact only with the patterns of greater height so that the absence of contact of the n-ranked pattern with the substrate prevents any exchange of energy related to the work of adhesion of the surfaces. This exchange of energy which is known to deform the printing patterns is thus limited to the last step of the method, precisely for the duration needed for printing.

It is assumed here that the width of the protrusions of the printing pattern is so small that the contact of these printing patterns with the substrate **32** cannot be detected by means of the sensor **60**.

Then, starting directly from the second contact position, a step **210** is performed for printing the imprint on the substrate **32**. At the end of the step **210**, in an operation **212**, the height of the stops **62** to **64** is lowered simultaneously and at the same speed by a travel distance Δ starting from the second contact position so as to directly attain a third contact position. The third contact position is chosen to ensure that the thickness D_3 of the incompressible space between the bottom **122**B and the face before the substrate ranges from $h_3/2$ to $9\ h_3/10$. Thus, the protrusions **134** of the printing pattern are slightly compressed against the substrate **32** but in no case are they completely crushed against the substrate.

To this end, for example, the course A is given by the following relationship:

$$\Delta=9(h_2-h_3)/10+3\times\mathrm{SFQR}_{max}$$

where SFQR_{max} is the measured value SFQR_{max} of the flatness of the substrate.

This travel distance ensures that the thickness D_3 is between $h_3/2$ and $9/h_3/10$.

Then, in an operation **214**, the pad is held in this third contact position for a time varying from one 1 millisecond to 15 minutes and preferably for a time of 0.5 seconds to 10 seconds.

In fact, the time during which the printing pattern must be held in contact with the face of the substrate **32** depends on the ink and the substrate as well as the material used to make the pad. The following table gives a few examples of contact time as a function of the type of ink, pad or substrate used:

Product to be transferred (ink)	Pad	Substrate	Contact time	Reference
Octadecyltrichlorosilane (OTS)	PDMS	SiO_2/Si Al	30 s	Jeon et al. Langmuir, 13 (13), 3382-3391 (1997)
OTS	PDMS	SiO2/Si	5 s	Xia et al. JACS 117, 9576-9577 (1995)
n-Alkanethiols with the general formula: HS—(CH2)n—CH3 including: (i) hexadecanethiol (HDT, n = 15) (ii)octadecanethiol (ODT, n = 17) (iii) eicosanethiol (ECT, n = 19)	PDMS	Ag Au	30 à 120 s	Balmer et al. Langmuir 21, 622-632 (2005)
HDT	PDMS	Ag Au	5 s	Xia et al. Langmuir 12, 4033-4038 (1996)
HDT	PDMS	Au	1 ms	Helmuth et al. JACS., 128, 9296-9297 (2006)
Dendrimers	PDMS-h	Pd	20 s	Jang et al. Langmuir 22, 3326-3331 (2006)
DNA	PDMS	Chemically functionalized glass	15 s to 2 minutes	Thibault et al. Journal of Nanobiotechnology 3:7 (2005)
DNA	PDMS	Functionalized glass	15 s	Lange et al. Anal. Chem., 76 (6), 1641-1647 (2004)
Proteins	PDMS	Functionalized glass	1-2 minutes	Inerowicz et al. Langmuir 18, 5263-5268 (2002)
Proteins	PDMS		1 s	Renault et al. J. Phys. Chem. B, 107 (3), 703-711 (2003)
Proteins	Agarose (hydrogel)	Functionalized glass	10 s	Mayer et al. Proteomics 4, 2366-2376 (2004)
Cellules	Agarose	Hydroxypatite porous tissue	15 minutes	Stevens et al. Biomaterials 26 7636-7641 (2005)
Bacteria	Agarose	Agar surface	5 s	Weibel et al. Langmuir 21, 6436-6442 (2005)

Once this contact time has elapsed, the computer again increases the height of the stops **62** to **64** at a step **220** to bring the pad **34** to its first and initial position where none of the protrusions of this pad are in contact with the substrate **32**.

Many other embodiments are possible. For example materials other than PDMS may be used to make the pad **34**. For example, poly(butyldiene), poly(dimethylsiloxane), poly (acrylamide), poly(butylstyrene) and their copolymers.

The above description, made in the case of the application of the pad **34** by a translation motion, can also be applied to a rotating pad in which the patterns come into contact with the substrate by a movement of rotation about an axis.

The shifting of the pad-holder to the substrate can also be obtained by shifting the substrate towards a fixed pad or by a combined motion of the pad and the substrate: the motion can be translational, rotational and/or a combination of the two.

For example, the means used to shift the pad-holder have been described here as a pneumatic jack. In other embodiments, these means for moving the pad-holder are a hydraulic jack or a motor-driven shaft with a dc stepping motor, a magnetic linear motor or any type of motor known to those skilled in the art. The shifting means can be manually controlled or computer-controlled with or without position control feedback systems.

Furthermore, the adjustable stop mechanism can be controlled or can be manually adjusted. It can be formed by motor-driven micrometer screws with a stepping motor or any other motor known to those skilled in the art with or without position control feedback. It can also be formed by motor-driven piezoelectric actuators with resolution of 1 to 10 nm and travel distance of 1 to 100 μm (see catalogue from the firms MElles Griot Inc. and Physik Instrument GmbH). According to a preferred embodiment, the adjustable stop measurement consists of a combined system: micrometer screws (motor-driven or manually shifted) to provide a wide course and a piezoelectric actuator with a position sensor and automatic feedback loop incorporated.

The stops **62** to **64** may be replaced by another stop mechanism such as a position control feedback system.

As a variant, the heightwise adjustable stops can form one piece with the pad-holder **36** and take support on the shoulder **66** forming one piece with the frame **48**.

When the substrate is made of a material transparent to visible light, the sensor **60** can be placed beneath the substrate and not above it as described with reference to FIG. **7**. This position is particularly well suited to situations where the substrate is made of glass and the pad is made out of an elastomeric material not transparent to visible light. For example the pad may be made of red Rhodorsil RTV 3255 with a Young's modulus in between that of PDMS-h and Sylgard 184.

The sensor **60** measures the difference between the pad and the substrate on a part of the pad and/or on a part of the substrate, for example on all or a portion of the patterns with a height h_i with i=1 to n−1 and on the entire surface or a part of the surface of the substrate facing it in order to deduce therefrom an item of information on parallelism between an ith flat bottom and the substrate.

Advantageously, the detection principle is adapted to resolving the pattern of height h_i. It is then appropriate to change the detection principle as and when contact is made by crushing the different levels of the pad. Many sensors known to those skilled in the art can be implemented in the microprinting device. For example and as a non-exhaustive example, they may be based on direct observation with a camera by reflection or transmission, interferometry or moiré effect, by confocal or nonconfocal microscopy, fluorescence detection etc. A combination of these principals may also be implemented, especially fluorescence detection by confocal microscopy. The pad-substrate contact can be detected at points localized by means known to those skilled in the art, for example, by capacitive effect, tunnel effect or by the passage of an electrical current.

Advantageously, the substrate-holder can also be mounted rotationally about axes parallel respectively to the directions X and Y. Actuators are used to adjust the angular position of the substrate holder above these axes. This increases the precision of the adjustment of the pad-substrate parallelism.

The mold used to make the pad **134** can be made by depositing material as an overlay on a plain base face. For example, this material may be the negative photopolymerizable resin SU8.

Advantageously, the part of the pad in contact with the pad-holder is molded with a housing that can take the pad-holder or a protruding part of the pad-holder so as to set up a mechanical link without any degrees of freedom between the pad and the substrate.

The inking of the pad can be done at different times during the microprinting method. For example, in a first stage, all the flush and contact positions are determined and memorized. Then the pad is brought to its initial position and inked. During this inking the conformation patterns can also be inked. Then, the pad is successively moved from its initial position to the first memorized flush position and then to the first memorized contact position followed by a possible stop of 0.5 to 10 seconds and then to the second flush position and then to the second contact position and so on and so forth until the printing pattern is put into contact with the surface of the substrate.

Certain levels i of the pad can be metalized, chemically functionalized or inked differently from the level n printing pattern as well as the surface facing the substrate to facilitate the adjustment of the device at the level i. For example, the protrusions of the levels i (i<n) of the pad and possibly the facing surface of the substrate are metalized to create a detectable interference field or again to detect their contact by passage of an electrical current. In another variant, these levels can be inked with fluorophores in order to detect the pad-substrate contact by emission of fluorescence detected by confocal microscopy. The detection of the contact of these protrusions with the substrate is then used to adjust the parallelism between the pad and the substrate.

The time during which the pad is kept in each of the contact positions is not necessarily the same from one contact position to the next one. Indeed, the duration of the contact can be made to vary level by level.

Advantageously, all the pads implemented in a pad microprinting operation are referenced relative to a same starting point which facilitates the overlay of patterns on the substrate.

As a variant, an operation for aligning the pad with the substrate is done in each flush position of a pattern having at least one protrusion whose position along the axes X and Y can be measured. To this end, the pad microprinting device includes one or more sensors capable of measuring the position of this protrusion along the X and Y axes. Finally, the alignment operation consists of the alignment in the plane X, Y of the substrate with respect to the pad (or conversely) before the contact of the protrusions with a height h_i of the pad (i=1 to n). To achieve this, the computer **80** sets the pad-substrate distance of the level i at the value D_i with $h_i<D_i<2\ h_i$. In particular, for the levels i, where i is greater than 1, the setting implies friction of the levels i−1 to 1 on the substrate with possibly a zone of exclusion for printing the pattern to be defined on the substrate.

The printing pattern may comprise positioning protrusions with a height h_n where the smallest width is at least twice and preferably at least ten times greater than the width L_n. The width L_n is sufficient for the difference between this positioning protrusion and the substrate **32** to be capable of being measured by the sensor **60**. Thus, through such positioning of protrusions, it is possible to carry out a more precise adjustment of the parallelism of the nth flat bottom with the face of the substrate **32**.

The hinging **42** can be replaced with other known hinge systems and especially those described in the following publications:

K.-B. Choi and J. J. Lee, Review of Scientific Instruments 76, 075106-6 (2005).

H. Lan, Y. Ding, H. Liu, and B. Lu, Microelectronic Engineering 84, 684-688 (2007).

The pad **34** can be designed to cover the entire surface to be printed of the substrate **32** in a single pass. Conversely, the pad **34** can be designed to print an imprint solely on a particular site k of the surface to be printed on. Then, the pad or the substrate is shifted so as to obtain the same print but on another particular site of the same substrate. The pad microprinting method is then lengthier than the previous one but the adjusting of the parallelism of the pad with respect to a particular site of the substrate can be done site by site, providing for more precise printing. For example, for each particular site k, the parallelism of the pad and of the substrate is adjusted as a function of the $SFQR_k$ value and not that of the $SFQR_{max}$ value.

FIG. **19** shows a variant in which the protrusions **300** of the (n−1)th pattern level are made out of a rigid material i.e. out of a material for which the Young's modulus is greater than 1 GPa.

One way to reduce the width of the exclusion zone is to limit the compression height needed to pass from one level to the other. For example, FIG. **10** shows a multi-level pad in which the nth flat bottom can be taken for none of the other flat bottoms demarcated by the conformation levels. In FIG. **10**, the pad is shown in the particular case where n is equal to 2. This pad has a first conformation pattern level formed by protrusions **312** and a second printing pattern level formed by protrusions **310**. In this variant, the second flat bottom from which the protrusions **310** protrude, cannot be taken for the first flat bottom demarcated by the protrusions **312**. Here, the second flat bottom and the first flat bottom are parallel. For example in FIG. **20**, the second flat bottom is spaced from the first flat bottom by a distance F_2. The distance F_2 is such that a sum of this distance F_2 and of the height h_2 is strictly smaller than the height h_1 of the protrusions **312**.

The compression height thus passes from h_1-h_2, if the first and second flat bottoms are indistinguishable from each other, to h_1-h_2-F_2. In taking h_1=10 μm, h_2=1 μm et F_2=7 μm, the compression height goes from 9 μm to 2 μm only, thereby concomitantly reducing the width of the exclusion zone. However, it is still greater than $h_1/10$ i.e. 1 μm, to provide for efficient contact of the first level on the entire surface of the pad.

This variant also has the advantage of limiting the travel distance needed to apply the printing pattern to the surface of the substrate.

FIG. **21** is a pad with three conformation pattern levels and one printing pattern level. In this figure, the protrusions of the first second and third conformation pattern levels respectively bear the references **400**, **402** and **404**. The protrusions of the printing pattern bear the reference **406**. The protrusions **400**, **402** and **404** respectively demarcate flat bottoms **410**, **412** and **414**. The flat bottoms **410**, **412**, and **414** are parallel to one another and are not indistinguishable from each other. Thus, the pad has as many flat bottom levels as it has conformation pattern levels.

The pad **34** is not necessarily made only of elastomeric material. In particular the layer of elastomeric material can be preceded by other layers of different hardness values made out of different materials.

The pad may be constituted heterogeneously with elastomers having different Young's modulus values. For example, the pad may be constituted by successive overmolding of the different homogenous elastomers having different hardness values. The pad can also be constituted by the molding of a master model with the addition of detachable elements that are removed or added on during the molding in a manner similar to the methods used in plasturgy. It is thus possible to make conformation levels with a plastomer having a low Young's modulus so as to limit the width Z_i of the exclusion zone and provide for printing patterns with a high Young's modulus so as to limit deformations during contact or again with a low interaction with the surface of the substrate so as to limit the influence of the work of adhesion. For example, the heterogeneous pad may be constituted by a sandwich structure of PDMS plastomer that is more rigid for the printing layer and more supple for the conformation patterns.

Another example of a pad constituted heterogeneously is represented in FIG. **22**. FIG. **22** shows a pad **500** having a first level of conformation pattern formed by protrusions **502** and a printing pattern **504** formed by protrusions **506**. In this variant, the printing pattern **504** is made out of an elastomeric material that is harder than the elastomeric material used to make the conformation pattern. For example, the elastomeric material used to make this printing pattern has a Young's modulus greater than 50 MPa and preferably greater than 90 MPa.

FIG. **23** represents a contactless method for printing an imprint on a substrate by pad microprinting. The method of FIG. **23** is for example identical to that of FIG. **12** except for the fact that the operation **212** is replaced by an operation **612**. During the operation **612**, the height of the stops **62** to **64** is adjusted to maintain the thickness D_3 of the incompressible space between h_3+1 nm and h_3+100 nm. Thus, the protrusions **134** of the printing pattern never come into contact with the face of the substrate. However, the space with a thickness of less than 100 nanometers between the end of the protrusions **134** and the face of the substrate is small enough to enable the ink to go through this space by ballistic diffusion. Thus, an imprint is formed by the face **32** without its being necessary to have direct contact between the protrusions of the printing pattern and the face of the substrate. This procedure prevents any exchange of energy related to adhesive stresses on the surfaces. This means that the protrusions of the printing pattern are not deformed, thus improving the quality of the print. The duration during which the thickness D_3 is maintained is between a minimum duration needed to provide for the transfer of the printing pattern to the substrate and a maximum duration that leads to deterioration of the imprint by diffusion. This duration may be determined experimentally.

FIG. **24** is a variant of the device **30** in which adjustable stops **620**, such as the piezoelectric actuators, with a vertical sense of motion, are distributed between the pad-holder **36** and the pad **34**. In FIG. **24**, only one adjustable stop **620** has been shown. More specifically, each of these stops has a supporting point on one face of the pad-holder pointed towards the substrate **32** and another supporting point on the upper face of the pad **34**. Thus, each of these stops is capable of locally modifying the curvature of the pad by varying the distance between its supporting points. Each of these stops can be controlled by the computer **80**.

Furthermore, the device **30** has a sensor **622** of defects of flatness on the substrate **32**. For example, this sensor is capable of measuring the amplitude in the direction Z of each flatness defect. This sensor can also measure the position in the plane X, Y of each of the flatness defects. The sensor **622** is connected to the computer **80**.

During the printing method, the sensor **622** measures the flatness defects of the substrate **32** and then crushes the pad **34** against the substrate **32** or at the same time as the pad **34** is crushed on the substrate **32**. Then, the computer **30** adjusts the height of the stops **620** to match the curvature of the pad **34** with the curvature of the substrate **32** as illustrated in FIG. **24**. For example, to this end, the same techniques are used as those described in the case of thin-mirror telescopes which are mounted on a set of piezoelectric actuators to correct the curvature of the mirrors online as a function of atmospheric turbulence.

Thus, the parallelism between the pad and the substrate can be improved even as the surfaces facing each other have a large number of peaks, valleys and ridges.

Adjustable stops can also be laid out between the substrate **32** and the substrate-holder **70** so as to locally modify the curvature of the substrate. What has been described with reference to the stop **622** applies identically to the stops between the substrate **32** and the substrate-holder **70**.

The teachings given here in the particular case of a pad with two and three levels can also be applied to a pad with more than three or four or even more pattern levels.

The contactless pad microprinting method in which the printing pattern never comes into contact with the face of the substrate can be implemented independently of the use of a multi-level pad.

The stop **62** to **64** distributed on two non-collinear axes for the adjusting or simultaneous modification of the heights of the stops may be implemented independently of the multi-level pad. Similarly, the use of adjustable stops between the pad-holder and the pad or between the substrate-holder and the substrate can be implemented independently of the use of a multi-level pad.

More generally, the characteristics of any one of the independent claims and especially the characteristics of the characterizing parts can be replaced by the characteristics of any one of the dependent claims.

The invention claimed is:

1. A pad comprising:

a layer of elastomeric material having a first flat bottom from which there protrude n successive levels of embossed patterns, classified in descending order of height h_i, where n is an integer greater than or equal to two, and wherein i is an index that represents the pattern level, with i being equal to one for the pattern for which the height h_i is the greatest,

a first pattern level, said first pattern level being a conformation level, enabling the first flat bottom to be coarsely parallelized with a face of a substrate, said pattern being formed by several protrusions of a height h_i, said protrusions defining at least three non-collinear support points on said face and around the first flat bottom, the height h_i being measured relative to said first flat bottom and in a direction perpendicular to said first flat bottom, and

an n^{th} pattern level, said n^{th} pattern level being a printing level, capable of coming into contact with the face of the substrate solely after the $(n-1)^{th}$ pattern level has thus been put into contact with said face, to print the imprint on the face of the substrate, said pattern being formed by one or more protrusions having a height h_n projecting perpendicularly from an n^{th} flat bottom that is the same as or is parallel to the first flat bottom and that is situated between the three supporting points of the first pattern level, the height h_n being between $h_{n-1}/2$ and $0.5\times \mathrm{SFQR}_{max}$, where SFQR_{max} (Max Site Frontside least sQuare focal plane Range) is a standardized measurement of flatness of the substrate, the height h_n of each protrusion being measured relative to the n^{th} bottom plate and perpendicularly to said n^{th} bottom plate,

wherein for each pattern of height h_i with i strictly smaller than n, an exclusion zone of width Z_i surrounding each protrusion of height h_i and in which no lower pattern is located, the width Z_i being greater than or equal to $15h_i$, and

wherein the printing pattern is made out of an elastomeric material having a Young's modulus between 0.10 and 100 MPa.

2. The pad of claim **1**, further comprising at least one intermediate level i of conformation patterns enabling a more precise parallelization of the n^{th} flat bottom with the face of the substrate on which the imprint must be printed, each intermediate level i being formed by several protrusions having a height h_i above a standardized SBIR (Site Backside Ideal focal plane Range) measurement of flatness of the substrate and below $h_{i-1}/2$, where h_{i-1} is the height of the protrusions of level i−1 the just greater conformation pattern, said protrusions defining at least three non-collinear supporting points arranged around the n^{th} flat bottom.

3. The pad of claim **1**, further comprising at least one air escape channel linking a space, situated between the protrusions of each pattern level, to the exterior of the pad in order to enable air likely to be imprisoned between the substrate and the pad to escape out of the pad when the pad is thrust against the face of the substrate.

4. The pad of claim **1**, wherein the height h_n is less than or equal to 100 micrometers.

5. The pad of claim **1**, wherein the height h_n is less than or equal to 1 micrometer.

6. The pad of claim **1**, wherein the height h_n is less than or equal to 0.3 micrometers.

7. The pad of claim **2**, further comprising at least one air escape channel linking a space, situated between the protrusions of each pattern level, to the exterior of the pad in order to enable air likely to be imprisoned between the substrate and the pad to escape out of the pad when the pad is thrust against the face of the substrate.

8. The pad of claim **7**, wherein the height h_n is less than or equal to 100 micrometers.

9. The pad of claim **7**, wherein the height h_n is less than or equal to 0.3 micrometers.

10. The pad of claim **1**, wherein the printing pattern is made out of an elastomeric material having a Young's modulus of between 10 and 100 MPa.

11. The pad of claim **1**, wherein the width Z_i is greater or equal to $25h_i$.

12. The pad of claim **1**, wherein the shape factor of the protrusions of the printing level is between 0.2 and 2, wherein the shape factor is defined as a ratio between height h_i and smallest width L_i.

13. The pad of claim **1**, further comprising an air escape channel linking a space between each of said protrusions and the exterior of the pad to enable air to avoid imprisonment between the substrate and the pad by escaping out of the pad when the pad is thrust against the face of the substrate.

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